

# Estimating Taylor Rules for the Norwegian Interbank Offered Rate

by

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## Preface

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All remaining errors or inaccuracies are my responsibility alone.

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# 1 Introduction

In monetary policy history, targeting inflation has not been the main objective for central banks, and official inflation targeting was first adopted by New Zealand in 1990. In the last decades, however, most industrialized countries have sought to implement this approach, as Norway did officially in 2001. The Norwegian economy is special, in that much of its success hinges on the oil and gas industry. In addition, unlike comparable small open economies in the eurozone, Norway has its own currency and conducts its own monetary policy. By having the opportunity to conduct monetary policy, Norway has more measures of stabilizing the economy. For example, while high oil prices would lead to higher production costs and lower output in Europe, Norway would benefit as it would see high profits from its oil companies, as well as from suppliers and services related to the oil industry. In such a setting the European Central Bank (ECB) would want to lower interest rates to stimulate the European economy, while Norway would prefer higher interest rates to dampen the Norwegian boom. On the other hand, euro-countries do not have to worry about speculators and large fluctuations in their currency.

After the financial crisis Norway has been much better off than most other European countries, and the Norwegian interest rate has been higher than the ECB interest rate. The Norwegian krone has been strong and Norges Bank has been reluctant to increase the interest rate in fear of further appreciation. In addition, inflation has not picked up and is below its target level and output growth has been moderate, both reasons why Norges Bank does not increase the interest rate at the current time. There are, however, some economists who argue for a higher interest rate than the current level. One of the problems Norway faces is that housing prices have risen more quickly than what wages have, which in the long run certainly may lead to some sort of the collapse should it continue. A result of this is that debt per household has increased which implies that a considerable percentage of households will have problems paying their bills if interest rates were to increase. This is something the governor of Norges Bank, Øystein Olsen, has expressed concerns about.

The main objectives of this thesis are to investigate whether Norges Bank is following the Taylor principle, whether stability in other variables than inflation and output gap is targeted, and whether the results are robust with regards to variable measures, horizons and sample periods.

Inspired by Clarida, Gali and Gertler (1998, 2000) we estimate forward looking reaction functions using generalized method of moments (GMM) as estimation method and find that inflation targeting has been an important objective for Norges Bank in our sample period from 1999 to 2012. Also,

the results suggest that inflation concerns have been greater than the output gap concerns. While the results are quite robust to different instrument sets in the baseline case, we find that different variable measures, different horizons and alternative specifications of the forward looking model renders volatile results. Further, there is clear evidence that Norges Bank smooths the interest rate. We find evidence which suggest that both foreign interest rates and housing prices are a concern for Norges Bank. In addition, we find that inflation concerns were higher before the financial crisis which suggests a structural break in the monetary policy reaction function at the financial crisis outbreak.

The rest of this thesis is organized as follows. Section 2 presents the monetary policy conducted by Norges Bank as well as previous literature on Taylor rule estimation. Section 3 looks at different Taylor rules and describes the theoretical model. Sections 4 and 5 respectively present the econometric procedure and the data used in the empirical analysis. Section 6 presents the empirical findings and discusses how the results from this thesis fit similar literature for Norwegian data. Finally Section 7 summarizes the findings, discusses the relevance of the results and proposes suggestions for future research.

## 2 Monetary policy and previous estimation of Taylor rules

In this section, we first describe the objectives of Norges Bank and how it operates. Then we look at how Taylor rules have been estimated earlier and why empirical findings differ both within and between countries.

### 2.1 Monetary policy in Norway

The central bank in Norway, Norges Bank, has since 1985, when the law known as the central bank law was implemented, had the responsibility of conducting monetary policy, credit policy and currency policy.<sup>1</sup> Norges Bank's other objectives are to issue coins and notes, to make sure that the Norwegian payment system is efficient, also in a global perspective, and to survey the monetary, credit, and currency markets. In March 2001, a monetary policy regulation promoted by the Ministry of Finance was incorporated. This regulation says that the monetary policy objective should be low and stable inflation, approximately 2.5 percent yearly inflation.<sup>2</sup> In addition, it says that Norges Bank should aim at stabilizing the Norwegian currency and expectations of the development of the Norwegian currency. It also says that the monetary policy should support the fiscal policy by stabilizing the development in output and employment. Such an approach is often called a flexible inflation targeting regime, because while the central bank's main focus is inflation stabilization, it does consider other objectives. The horizon of the inflation target is not stated in the regulation, but Norges Bank declares that the current horizon is 1-3 years (Norges Bank, 2012*a*). Until the Norges Bank inflation report presented in July 2004 the inflation horizon for Norges Bank was 2 years. The inflation target of 2.5 percent is higher than the target of the Federal Reserve and the Bank of England, which is 2 percent, and the European Central Bank (ECB), which is below but close to 2 percent. Although marginal, there are both possible gains and losses from having a higher inflation target than 2 percent. A higher target makes it slightly easier for the government to stabilize or reduce real wages, as the public has a tendency to think in nominal terms rather than in real terms. Another gain is that Norges Bank has more maneuverability when determining the real interest rate. Given equal real interest rates the central bank with the higher inflation can reduce the nominal interest rate the most, although neither to a lower level than 0 as a negative nominal interest rate is impossible

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<sup>1</sup>Cf. "Lov om Norges Bank og pengevesenet mv. (Sentralbankloven) § 1"

<sup>2</sup>Cf. "Forskrift om pengepolitikken § 1"



to implement.<sup>3</sup> The potential losses of having a slightly higher target than 2 percent are mostly due to "menu costs", the fact that firms have to change prices more frequently, which poses some administrative costs.

Like most central banks, Norges Bank reasons its monetary policy decisions according to a loss function which looks like this (Norges Bank, 2012a):

$$L = (\pi_t - \pi^*)^2 + \lambda(y_t - y_t^*)^2 + \gamma(i_t - i_{t-1})^2 + \tau(i_t - i^*)^2 \quad (1)$$

Here the first expression represents the inflation gap, the second expresses the output gap, the third is the gradualism or smoothing factor and the last one says something about how far we are from the normal key policy rate.<sup>4</sup> The size of the coefficients suggests how much Norges Bank considers each deviation, and we see from the quadratic form of the loss function that positive and negative gaps are looked at as equally damaging to the economy. In the first monetary policy report by Norges Bank of 2011 the lambda-coefficient was only 0.1, while in the last monetary policy report of 2012 the coefficient was 0.75 (Norges Bank, 2012b). This suggests that the weight on output has increased the last two years, which also means that Norges Bank continuously updates this coefficient, hence the loss function changes over time.

The main instrument for the central bank to control inflation is the key policy rate, which is the rate commercial banks get from deposits in the central bank. This is the "floor" of the interest rate corridor, while the "ceiling" is the interest rate on bank's overnight loans. The interbank lending rate is the average lending rate between commercial banks in Norway. This rate is within the interest rate corridor, hence higher than the key policy rate. The interbank lending rate is what affects consumers directly, which is the reason why we choose to estimate this rate instead of the key policy rate. Higher interbank lending rates means that the cost of borrowing gets higher for the banks, which leads to banks requiring more margin on loans they give to consumers. This means that consumers will have less disposable income and consume less, which will dampen aggregated demand. Hence, in theory, the rate of inflation should be reduced.

Norges Bank claims that it does not use a Taylor rule explicitly other than as a cross reference when making monetary policy decisions. In fact, Norges Bank uses, in combination with other models, a macroeconomic model called the Norwegian Economic Model (NEMO), which minimizes a loss function

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<sup>3</sup>A negative nominal interest rate would mean that people would withdraw all their assets, as banks would charge for deposits

<sup>4</sup>In Norges Bank (2012a) the normal key policy rate is expected to be around 4% the next few years

such as (1). By using NEMO, Norges Bank uses a method of calibration rather than estimation when projecting the interest rate path. However in Norges Bank (2013), the central bank argues that the loss function does not consider financial instabilities. Hence, the interest rate path that it assumes in this report is higher than what a strict technical analysis would produce. Rather than adding financial instability to the loss function, Norges Bank uses a certain kind of discretion when setting the interest rate.

Basically there are two ways to conduct monetary policy. The central bank could either follow an interest rate rule or it can optimize the decision in each period. The latter is also called the method of discretion. A simple interest rate rule may look like this:

$$i_t = \alpha + \beta\pi_t + \gamma x_t , \quad (2)$$

where  $i_t$  is the interest rate in period  $t$ ,  $\pi_t$  is inflation in period  $t$  and  $x_t$  is the output gap in period  $t$ .  $\alpha$ ,  $\beta$  and  $\gamma$  are coefficients.

By using the other option, that is optimizing in each period, the loss is minimized when looking at each period individually. Formally this would mean minimizing (1) in each period. Because we in this thesis implicitly assume that Norges Bank follows an interest rate rule, we do not discuss the potential gains and losses from each of the two "options".

## 2.2 Why empirical results for reaction function estimations differ

There are several reasons why results from the interest rate reaction function estimations differ widely both within economies and between economies.

### 2.2.1 Inflation

Inflation and the inflation gap could in some cases be hard variables to measure. Not until the end of the 1990s, central banks started to adopt inflation targeting as a monetary policy target, hence estimating a reaction function before this period could pose problems. Another issue is that some central banks do not have a specific inflation target. For example, the ECB has a target inflation of close to but below two percent. There are for most countries also big differences between the different types of inflation measures. For example, it matters whether a researcher chooses the ordinary consumer price index inflation or the consumer price index inflation that excludes food and energy when estimating a reaction function. This will be further described in the data section, but the insight is that larger inflation fluctuations could influence the parameters and their level of significance in an empirical model.

### 2.2.2 Output gap

The output gap is inherently hard to measure, and there are two main reasons for this. First of all, in order to calculate the output gap there must be a trend to compare with. Some use a quadratic trend (Clarida, Gali and Gertler, 1998), some use a linear trend (Taylor, 1993), while some use the Hodric-Prescott filter or other filters to measure the trend (Esanov, Merkl and de Souza, 2005). When using most of these methods there are several variants of each of them. All these possibilities can potentially lead to different results in an estimation. For example, while Hodrick and Prescott (1997) suggests a coefficient of 1600 on quarterly data for the HP-filter, Statistics Norway uses 40 000. The other big problem related to measuring the output gap is output uncertainty and the difference between real time data and revised data. Seitz, Gerberding and Worms (2006) look at the numbers in Clarida, Gali and Gertler (1998), for the Bundesbank, and find that when using real time data, there is no evidence of the Bundesbank targeting inflation, contrary to the results of Clarida, Gali and Gertler (1998). Seitz, Gerberding and Worms (2006) suggest replacing the level of the output gap with the *change* in the output gap, in order to reduce the deviation between real time and revisited data.

### 2.2.3 Variants of the Taylor rule

Different types of Taylor rules yield different results. Rules can be backward looking or forward looking. What this means is that we can either assume that the central bank looks at past inflation and output, or the expected inflation and output for future periods, when setting the interest rate. Rules can also be hybrid, which means that the central bank considers both lagged values of variables *and* future expected variables when setting the interest rate. Taylor's original rule is backward looking, but several recent versions of the rule include an expectation factor. Clarida, Gali and Gertler (1998) reject the backward looking rule in favour of a forward looking rule. However, they include the lagged interest rate as a regressor, thus formally making it a hybrid rule. In their proposed rule they use lagged values of variables as instruments for the expected levels of the regressors. Clarida, Gali and Gertler (2000) implement a backward looking rule and the results reflect the forward looking rule. In particular, they write:

In sum, while we view the forward-looking specification as more plausible a priori, our key insights also obtain from the backward-looking specification.

The coefficient for the lagged interest rate variable is often called the smoothing parameter. In most estimations when including this variable, researchers find this smoothing parameter to be highly significant and in some cases the size of it is close to unity. Rudebusch (2002) however proposes that smoothing coefficients do not actually reflect smoothing but that they

(...) reflect serially correlated or persistent special factors or shocks that cause the central bank to deviate from the policy rule.

Hence, Rudebusch (2002) suggests that the lagged interest rate may not enter the actual policy rule at all, and he argues that there is some sort of misspecification in the models proposed by for example Clarida, Gali and Gertler (1998). English, Nelson and Sack (2003) and Gerlach-Kristen (2004) partially support some of the views presented by Rudebusch (2002) by showing that adding variables as regressors in a Taylor rule for U.S. data makes the smoothing parameter drop. However, they both reject the notion of Rudebusch (2002) that there may be no monetary policy inertia. Castelnovo (2003) employs the empirical model of English, Nelson and Sack (2003) and finds that interest rate smoothing is *not* induced by an omitted variable bias when looking at a Taylor rule in first differences. Smets (2002) argues that when there is output gap uncertainty, responses are less aggressive than what they otherwise would be, hence increasing the smoothing parameter.

Some researchers include other variables such as money supply, the exchange rate and the stock exchange index, with various conclusions. Puckelwald (2012) estimates both backward looking and forward looking Taylor rules for 20 OECD countries and adds the nominal exchange rate deviation from a long term level and the real interest rate deviation from a base country as regressors in such a reaction function. He finds that in most cases, countries that have significant coefficients for the exchange rate deviation and/or the real interest rate deviation, have lower values for their coefficients for output gap and inflation. Hence, he suggests that these countries conduct a less active monetary policy. Clarida, Gali and Gertler (1998) find that although there are some changes, adding variables in most cases do not change the coefficients for inflation, the output gap or for the lagged interest rate substantially when looking at the U.S., Germany, Japan, France, Italy and the U.K. from the end of 1979 until 1993 - 1994. Belke and Klose (2010) look at the ECB and the Federal Reserve from 1999 until 2009 and find that while most variables that are added become significant in a GMM-type estimation, the baseline coefficients do not change much and rarely so the sign or degree of significance. Siklos, Werner and Bohl (2004) estimate a variety of different reaction functions for different European countries and find that the results are highly volatile. They conclude that additional information variables should not be added as regressors to the Taylor rule, but that they could be added to the instrument set in a GMM approach to achieve a better fit and the most plausible results. Other than the lagged value of the interest rate, most agree that the two most important regressors for a monetary policy reaction function inflation and the output gap.

#### **2.2.4 Structural breaks and observation frequency**

One of the reasons that results may differ is the possibility of structural breaks. For example inflation targets may change as new political guidelines are implemented. In addition, in many countries the central bank is independent, thus it can within the bounds of the guidelines in theory conduct monetary policy as it pleases. Hence changes within the central bank may also lead to structural breaks. Inflation targets and horizons for the monetary policy may also change. Clarida, Gali and Gertler (2000) divide the U.S. post war era into three parts and find large differences in the estimated coefficients. For example, for the backward looking estimates the coefficient for inflation was 0.86 in the Pre-Volcker period, 1.72 in the Volcker-Greenspan period and 2.55 in the Post-82 period. Belke and Klose (2010) look at both the Federal Reserve and the ECB from the start of 1999 and they find that while the two central banks operated quite similarly until the financial crisis

started, their policies changed in time of crisis. In the sample period 2007M8 - 2009M6 Belke and Klose (2010) find that the ECB was aiming at stabilizing inflation at the cost of some output gap losses while the Federal Reserve was aiming at stabilizing the output gap at the cost of higher inflation. Mishkin (2009, 2010) claims that monetary policy inertia is less significant during a financial crisis than otherwise. This is supported by Belke and Klose (2010) who find that the smoothing parameter was higher in the years before the financial crisis, than in the time of the crisis, both for the ECB and for the Fed.

When estimating Taylor rules for the ECB and the Federal Reserve Belke and Klose (2010) argue that in order to catch the dynamics of the Taylor rule properly, monthly instead of quarterly data should be used. Islam (2011) on the other hand estimates both forward and backward looking rules for U.S. data and finds that the results do not vary with the data frequency being monthly or quarterly.

### 2.2.5 Estimation methods

Empirical results will in most cases differ with various estimation methods, and there are several possibilities when deciding which estimation method to apply when estimating Taylor rules. Seitz, Gerberding and Worms (2006) claim that the generalized method of moments (GMM) estimation in Clarida, Gali and Gertler (1998)

(...) has become standard in the empirical analysis of monetary policy decisions.

GMM estimations have been done for big economies such as Germany (Clarida, Gali and Gertler, 1998; Siklos, Werner and Bohl, 2004) and the U.S (Clarida, Gali and Gertler, 2000; Chadha, Sarno and Valente, 2004), but also for small open Economies such as Sweden (Jia, 2011), Taiwan (Yau, 2010) and Slovakia (Maria-Dolores, 2005). In addition to GMM, the method of maximum likelihood method is also commonly used when estimating forward looking Taylor rules, such as in e.g. Gozgor (2012) and de Losso (2012). Most backward looking estimations that include a smoothing parameter relies on a nonlinear estimation method such as nonlinear least squares (Hofmann and Bogdanova, 2012) or two stage non linear least squares (Weise and Krisch, 2010). Backward looking estimations without a smoothing parameter can be done with ordinary least squares (OLS)(Taylor, 1993) or two stage least squares estimation (Castelnuovo, 2007) if we suspect endogenous right hand side variables.

### 3 Theoretical framework

In this section, we present the original Taylor rule and show theoretically how we can expand the rule to include a smoothing parameter and make it forward looking.

#### 3.1 The original Taylor rule

The original Taylor rule was proposed by Taylor (1993) who looked at how the Federal Reserve had conducted monetary policy in the years 1987-1992.

$$i = p + 0.5y + 0.5(p - p^*) + 2 \quad (3)$$

where  $i$  is the federal funds rate,  $p$  is the four quarter inflation rate,  $y$  is the percent deviation of real GDP from a target and  $p^*$  is the inflation target. Because the inflation target is 2 the rule can be reduced to this:

$$r = 1 + 1.5p + 0.5y \quad (4)$$

Hence, when both inflation and output were at their respective target levels, the "equilibrium" federal funds rate was 4 and hence the "equilibrium" real rate was 2. The rule suggested above was chosen because of its simplicity and because it "captured the spirit of the recent research". Taylor (1993) also introduced the notion that one should not follow these kind of interest rate rules mechanically, but rather think of them as a helpful indication for what needs to be done. Along with the Taylor rule came the "Taylor principle", which says that the nominal interest rate should react more than one-to-one to changes in inflation. This means that if there is a shock, such that inflation rises above the target level by one percentage point, the nominal interest rate should increase by more than one percentage point, in order to increase the real interest rate and dampen the shock. If the increase in nominal interest rate is less than one percentage point, the real interest rate will decrease after a shock, which would then have further accommodated the shock. The mechanics of the Taylor rule is called "leaning against the wind", meaning that an increase in inflation or output should be responded with an increase in the nominal interest rate to dampen the economy, and similarly a reduction would boost the economy if inflation or output decreased.

#### 3.2 The interest rate target in a forward looking Taylor rule

The original rule Taylor is a backward looking rule. This means that in period  $t$ , the central bank sets interest rate  $r_t$  based on the inflation from

$t - 1$  (given a one period target horizon) until  $t$  and the output gap in the last period i.e.,  $t - 1$  until  $t$ . Such a rule says that the only variable values one should consider when setting the interest rate are the last period inflation and output gap.

The original Taylor rule does not consider expected inflation and output in future periods. This is why most researchers find a forward looking Taylor rule to be more realistic when an expectation term is implemented. Inspired by the work of Clarida, Gali and Gertler (1998) and Clarida, Gali and Gertler (2000) we start off with a target rate  $i_t^*$ . What this means is that for each period, the central bank has a target for the nominal interest rate that they wish to get to. The target rate in period  $t$  is:

$$i_t^* = i^* + \beta(E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma E[x_{t,q}|\Omega_t], \quad (5)$$

where  $i^*$  is the "equilibrium" nominal interest rate, i.e., the rate that prevails when both expected inflation and output is on target.  $\pi_{t,k}$  is the annual inflation rate between period  $t$  and period  $t + k$ . Note that this implies that the inflation variable series will be slightly different for different horizons.  $x_{t,q}$  is the average output gap between period  $t$  and period  $t + q$ . Also in this case variable series will be slightly different for different horizons.  $\beta$  and  $\gamma$  are the coefficients for the inflation gap and the output gap respectively, and  $\Omega_t$  is the information set at time  $t$ . This means that the values of expected inflation and expected output gap is based on all the information the central bank has at that point in time. To simplify the model somewhat, we can introduce a constant term  $\alpha = i^* - \beta\pi^*$ , so that we get

$$i_t^* = \alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t] \quad (6)$$

We can easily transform this equation to the original backward looking model by setting  $k$  and  $q$  equal to -1. Setting  $q$  and  $k$  to be positive numbers will make the equation forward looking. Norges Bank has a target horizon of 1 - 3 years which would imply a  $k$  between 4 - 12 as we use quarterly data. As there is no explicit horizon for the output gap we assume it to be rather short, hence  $q$  is set to 1 and 2 as Clarida, Gali and Gertler (2000).

### 3.3 The forward looking Taylor rule with interest rate smoothing

Until now we have only considered the target rate, which is where the central bank prefers the interest rate to be in order to close the deviations from the targets. It is, however, widely recognized that central bankers tend to smooth interest rates. There are several reasons for this, but most importantly the



central bank wants to avoid large fluctuations in the interest rates in order to avoid large fluctuations in the value of assets. Interest rate smoothing is mentioned in the Norges Bank monetary policy report as the importance of gradualism. It is recognized that interest rates are "upward-rigid" which means that large reductions in the interest rate are more common than large increases.

We have from equation (6) the interest rate target, which is decided by expected inflation, expected output and a constant term. If we include interest rate smoothing we have to create an expression for the *actual* nominal interest rate. Hence some weight will be put on the target  $i^*$  and the rest will be decided by how important it is for the central bank to smooth interest rates, the size of  $\rho$ . For the objective function we then have:

$$i_t = (1 - \rho)i_t^* + \rho i_{t-1} + \nu_t \quad (7)$$

Here,  $\rho$  is the smoothing coefficient. We also have an exogenous interest rate shock term  $\nu_t$  with zero mean. Now we can insert the target rate (6) into (7) so that we get a rule for the actual nominal interest rate:<sup>5</sup>

$$i_t = (1 - \rho)(\alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t]) + \rho i_{t-1} + \nu_{1t} \quad (8)$$

Most researchers find that a smoothing consideration is present in most central banks, and this is found to be very high in some cases. Suppose for example that  $\rho = 0.9$  then the interest rate *target* (6), which the central bank thinks is optimal, is only approached by 10% of what it would have, had there been no smoothing. Consider a  $\beta$  with the value 1.5. This means that to dampen a positive shock on inflation by 1 percentage point, assuming the output gap is zero, the target rate would say that one should increase the interest rate say by 1.5 percentage points. However, because of smoothing the increase would only be 10% of 1.5, hence the increase would be 0.15 percentage points.

We can also check whether other variables have any effect on the interest rate, i.e., whether Norges Bank consider other variables when setting the interest rate. We can call this additional regressor  $h_t$  and its coefficient *eta*. What we do is to include the expected value of this additional variable to expand the target function (6) and we get

$$i_t^* = \alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t] + \eta E[h_t|\Omega_t] \quad (9)$$

Inserting this new target into the objective function (7) we get

$$i_t = (1 - \rho)(\alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t] + \eta E[h_t|\Omega_t]) + \rho i_{t-1} + \nu_{2t} \quad (10)$$

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<sup>5</sup>Note that the equation is no longer linear in the parameters

By using a similar procedure we can add two additional regressors, and the rule for the actual nominal interest rate will end up like this:

$$i_t = (1-\rho)(\alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t] + \eta_1 E[h_{1t}|\Omega_t] + \eta_2 E[h_{2t}|\Omega_t]) + \rho i_{t-1} + \nu_{3t}, \quad (11)$$

where  $h_{1t}$  and  $h_{2t}$  are the additional regressors, and  $\eta_1$  and  $\eta_2$  are their respective coefficients.

## 4 Econometric procedure

In this section, we first explain why GMM has been chosen as the estimation method. Further, we explain the general theory behind GMM, and implement this method into the Taylor rules described in Section 3. Finally we explain the intuition behind the test of overidentifying restrictions, the J-test.

### 4.1 Why OLS could be problematic

The original Taylor rule does not take account of interest rate smoothing, which means that it is linear in parameters and could be estimated with linear methods such as ordinary least squares or two-stage least-squares. However, because we include a smoothing parameter, parameters are non-linear, which is a violation of the OLS-assumptions that ensure unbiased and consistent estimators. Hence non-linear estimation methods should be used in our context.

Because we use a forward looking rule, we assume that the central bank considers the expected inflation in a future period when changing the interest rate, rather than current inflation. In Clarida, Gali and Gertler (1998) when checking whether this is true, they find that for none of the central banks they look at, lagged inflation is statistically significant. Hence, they reject the backward-looking specification in favour of their forward-looking specification. When using a forward looking rule the expected explanatory variables will be endogenous, i.e., correlated with the error term at time  $t$ . Hence, even if we used a linear forward looking rule, OLS would still be a problem due to violation of zero conditional mean for the error term. In order to solve the problems of non-linear parameters and endogeneity in the lead variables, we use generalized method of moments. As noted by Biorn (2012), GMM can handle endogenous right hand side variables in non-linear equations. It can also handle residual heteroskedasticity and residual autocorrelation in equations whose right-hand side variables are correlated with the disturbances. In addition, GMM does not (as Maximum Likelihood estimation) rely on strong distributional assumptions for the disturbances. It can, for instance, handle situations with skewed distributions.

### 4.2 GMM in general

In the general GMM model we have the equation

$$\mathbf{y}_t = \mathbf{h}(\mathbf{X}_t; \boldsymbol{\theta}) + \boldsymbol{\epsilon}_t, \quad t = 1, \dots, T \quad (12)$$

Here  $\mathbf{y}_t$  is the explained variable vector, which is determined by a function  $\mathbf{h}$  of the explanatory variable matrix  $\mathbf{X}_t$  and the parameter matrix  $\boldsymbol{\theta}$  of appropriate dimensions, in addition to a vector of an error term  $\boldsymbol{\epsilon}_t$ .  $T$  is the sample length. We introduce an instrument matrix  $\mathbf{Z}_t$  which is correlated with  $\mathbf{X}_t$ . Then, we define the orthogonality condition, which says that the instrument should be uncorrelated with the disturbance:

$$E[\mathbf{Z}_t' \boldsymbol{\epsilon}_t] = \mathbf{0} \quad (13)$$

Substituting for  $\boldsymbol{\epsilon}_t$  from 12 gives:

$$E[\mathbf{Z}_t'(\mathbf{y}_t - \mathbf{h}(\mathbf{X}_t; \boldsymbol{\theta}))] = \mathbf{0} \quad (14)$$

Hence, if we define the function  $\mathbf{f}(\cdot)$  to be:

$$\mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t) = \mathbf{Z}_t'(\mathbf{y}_t - \mathbf{h}(\mathbf{X}_t; \boldsymbol{\theta})) \quad (15)$$

we can write the orthogonality condition as

$$E[\mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t)] = \mathbf{0} \quad (16)$$

This is the theoretical expectation. We can now create an expression for the empirical mean of the values of  $\mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t)$ , which we can define as

$$\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t) = \frac{1}{T} \sum_{t=1}^T \mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t) = \frac{1}{T} \sum_{t=1}^T \mathbf{Z}_t'(\mathbf{y}_t - \mathbf{h}(\mathbf{X}_t; \boldsymbol{\theta})) \quad (17)$$

Now, from the definition of the GMM estimator in a general model, we want to choose the estimator of  $\boldsymbol{\theta}$  which brings  $\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t)$  as close to the zero value of its theoretical counterpart  $E[\mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{Z}_t, \mathbf{X}_t)]$  as possible.

### 4.3 Implementing GMM in a Taylor rule setting

In particular, we have from (8)

$$i_t = (1 - \rho)(\alpha + \beta E[\pi_{t,k} | \Omega_t] + \gamma E[x_{t,q} | \Omega_t]) + \rho i_{t-1} + \nu_{1t} \quad (18)$$

In the following it will be beneficial to introduce an auxiliary variable  $\epsilon_{1t}$ .

$$\epsilon_{1t} = -(1 - \rho)(\beta(\pi_{t,k} - E[\pi_{t,k} | \Omega_t]) + \gamma(x_{t,q} - E[x_{t,q} | \Omega_t])) + \nu_{1t} \quad (19)$$

We see that this expression is a combination of forecast errors and the exogenous error term and it is thus orthogonal to any variable in the information set. We can solve this equation for  $\nu_{1t}$  to get:

$$\nu_{1t} = (1 - \rho)(\beta(\pi_{t,k} - E[\pi_{t,k} | \Omega_t]) + \gamma(x_{t,q} - E[x_{t,q} | \Omega_t])) + \epsilon_{1t} \quad (20)$$

and insert (20) into our actual nominal interest rate function (18) to get:

$$\begin{aligned} i_t = & (1 - \rho)(\alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t]) + \rho i_{t-1} \\ & + (1 - \rho)(\beta(\pi_{t,k} - E[\pi_{t,k}|\Omega_t]) + \gamma(x_{t,q} - E[x_{t,q}|\Omega_t])) + \epsilon_{1t} \end{aligned} \quad (21)$$

The expectation terms disappear and we are left with:

$$i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t} \quad (22)$$

This is what we can call the policy reaction function, and it is precisely this we want to estimate. By algebraic manipulation we removed the expectation terms so that we now can write the policy reaction function in terms of observed variables.

We use an instrument set  $\mathbf{Z}_t$  within the information set  $\Omega_t$ , which is orthogonal to  $\epsilon_{1t}$ . Variables included in the instrument set can be any lagged variables and any current variables that are uncorrelated with  $\epsilon_{1t}$ . Hence, we have the condition  $E[\epsilon_{1t}|\mathbf{Z}_t] = 0$  which we can write as

$$E[i_t - (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) - \rho i_{t-1}|\mathbf{Z}_t] = 0 \quad (23)$$

Hence, the parameter vector we want to estimate is  $[\rho, \alpha, \beta, \gamma]$ . Because we in our empirical analysis use more instruments than there are parameters, the number of orthogonality conditions exceed the number of parameters to be estimated. Hence, the model is over-identified and we must test the validity of the over-identifying restrictions.

Note that when estimating (8), we will get a constant term  $\alpha = i^* - \beta\pi^*$ . We will get to know  $\beta$ , but we will not be able to determine the values of  $i^*$  and  $\pi^*$  directly from the estimation. We know, however, that the inflation target  $\pi^*$  in Norway is 2.5 percent and has been so since the start of our sample period. Hence to find our implied long-run nominal equilibrium rate, we can use the constant term  $\alpha = i^* - \beta\pi^*$  and simply solve this equation for  $i^*$ .

We also want to look at a policy reaction function where additional regressors are included. We have from (10):

$$i_t = (1 - \rho)(\alpha + E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t] + \eta E[h_t|\Omega_t]) + \rho i_{t-1} + \nu_{2t} \quad (24)$$

To end up with a policy reaction function in terms of observed variables such as (22) we perform the same procedure as before. The only difference is that the term that consists of forecast errors and the exogenous disturbance has to be slightly rewritten. By doing the calculations, we get a policy reaction function for the expanded Taylor rule:

$$i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t} \quad (25)$$

It is straightforward to add additional variables by following this procedure to get a policy reaction function for the further expanded Taylor rule:

$$i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}) + \rho i_{t-1} + \epsilon_{3t} \quad (26)$$

#### 4.4 The J-test

The J-test, also known as the test for overidentifying restrictions, can be performed as long as there are more orthogonality conditions than parameters. As mentioned earlier, we want to choose the estimator of  $\boldsymbol{\theta}$  which brings  $\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)$  as close to the zero value of its theoretical counterpart  $E[\mathbf{f}(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)]$  as possible. Under the null hypothesis of the J-test

$$\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t) = \mathbf{0} \quad (27)$$

The alternative hypothesis is that

$$\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t) \neq \mathbf{0} \quad (28)$$

Hence, if the model fits the data well,  $\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)$  is close to zero, in which case we do not reject our null hypothesis. On the other hand if  $\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)$  is far from zero, we reject the overidentifying restrictions imposed on the model. Exact calculations of the test statistic can be found in the appendix.

## 5 Data

In this section, we present the data used in the empirical analysis. In subsection 5.1 we present the time series used in the estimations and include figures for each of the variables. In subsection 5.2 we present the sample periods used when checking for structural breaks, while in 5.3 we discuss stationarity and unit root tests.

### 5.1 Time series

We first look at the original Taylor rule variables, and then proceed by presenting variables used as instruments and variables used as regressors. We have used OxMetrics6 to create the figures presented in this section.

#### 5.1.1 The interest rate

As a measure for short term nominal interest we use the three month Norwegian Interbank Offered Rate (NIBOR) in annual terms. NIBOR is calculated by taking the trimmed mean interest rate from six panel banks that operate in Norway, such that the maximum and the minimum values are omitted.<sup>3</sup> These interest rates are supposed to reflect what rates the banks require in order to lend to other banks, and they should be seen as market rates rather than binding offers. We use the monthly averages from the NIBOR-statistics supplied by Norges Bank to create a quarterly average. The money market rate can be used as a proxy for the short term nominal interest rate which is what we want to estimate. In figure 1 we can see how the NIBOR has evolved.

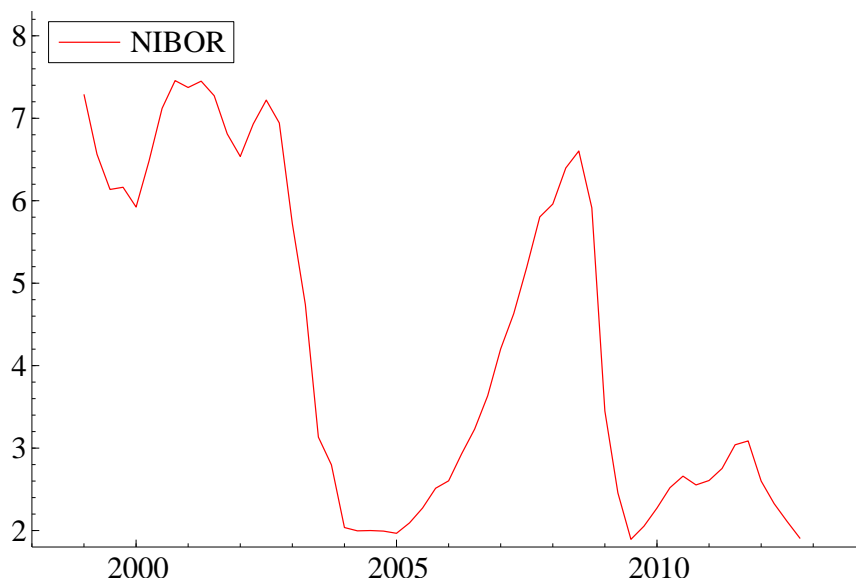
#### 5.1.2 Inflation

We use the consumer price index adjusted for tax changes and excluding energy commodities, the CPIATE-index, to construct a measure for inflation. This is also called core inflation in Norway. It is reasonable to exclude energy commodities for small open economies like Norway because these prices can be taken as exogenous and says little about price changes in Norway. By taking the log of the CPIATE-index, we can find the four quarter log difference which is a measure for the 1-year horizon inflation. For robustness checks, we also use the CPI-index in the empirical analysis. Figure 2 shows

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<sup>3</sup>The banks are DNB Bank ASA, Danske Bank, Handelsbanken, Nordea Bank Norge ASA, SEB AB and Swedbank

Figure 1: The interest rate



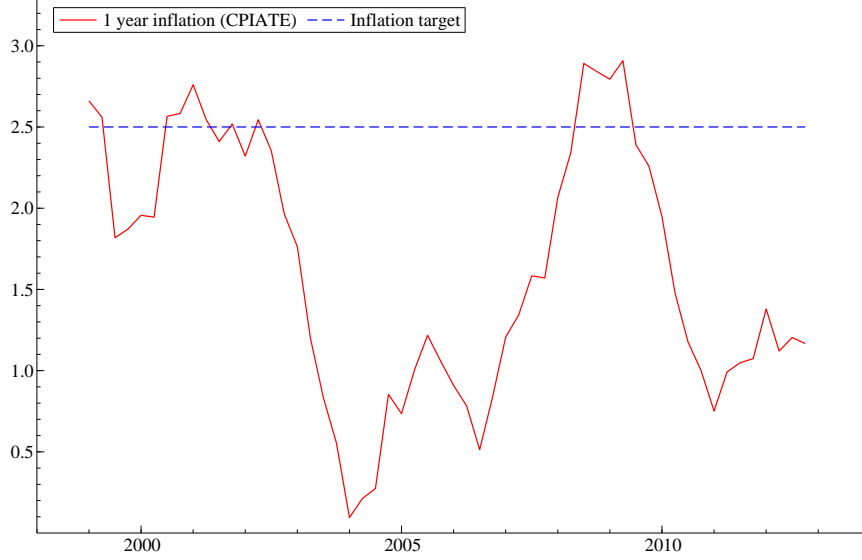
the movements in the CPIATE-measured inflation. We see that for most of our sample period inflation has been below target.

### 5.1.3 The output gap

To obtain a measure of the output gap, we first look at the gross domestic product for mainland-Norway with a four quarter smoothing average. Mainland Norway consists of all domestic production activity except from exploration of crude oil and natural gas, services activities incidental to oil and gas, transport via pipelines and ocean transport. If the oil and gas industry was included, we would see larger fluctuations in output, which would be largely affected by exogenous shocks, something that could disturb our estimation results. It may be thought of as a paradox that Norway is completely reliant on its oil industry, while at the same time we do not consider the oil industry when calculating inflation and the output gap. However, we want to look at how Norges Bank reacts to what it knows. Supply and demand shocks in the oil and gas sector are hard if not impossible to forecast and are not affected by Norges Bank at all. To find the output gap, we have to look at output compared to a trend. By only using data for the Norwegian GDP, we can create a trend variable. This can be done by using a Hodric-Prescott



Figure 2: Inflation



filter, which minimizes an equation with regards to the trend component:

$$\text{Min}_{\tau}(\sum (y_t - \tau_t)^2 + \lambda \sum [(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2) \quad (29)$$

Here,  $y_t$  is actual output in period  $t$  and  $\tau_t$  is the trend at time  $t$ . The  $\lambda$  suggested by Hodrick and Prescott (1997) for quarterly data is 1600. Statistics Norway, however, uses a  $\lambda$  value of 40 000, as they argue that such a trend fits the Norwegian economy better than what 1600 does. We will in the baseline forward looking model case use 40 000, which is suggested by Statistics Norway, but also try using 1600 to check if the results are robust. The effect of a change in  $\lambda$  can be illustrated quite simply. Let us say lambda is 0, then the trend equals the output gap, hence the "trend" would be actual output  $y$ . When lambda goes to infinity the trend approaches a straight line, like the one used by Taylor (1993).

The trend may change depending on which sample period we use to create the trend. It seems reasonable here to use the longest possible sample period obtainable to capture the right trend. Hence, even though we use the period 1999Q1 - 2012Q4 when estimating, we use a longer sample (1978Q3 - 2012Q4) to create the trend  $\tau$ . From this it is straightforward to obtain a measure of the output gap (OG):

$$OG = \left(\frac{y - \tau}{\tau}\right)100 \quad (30)$$

Figure 3: The output gap

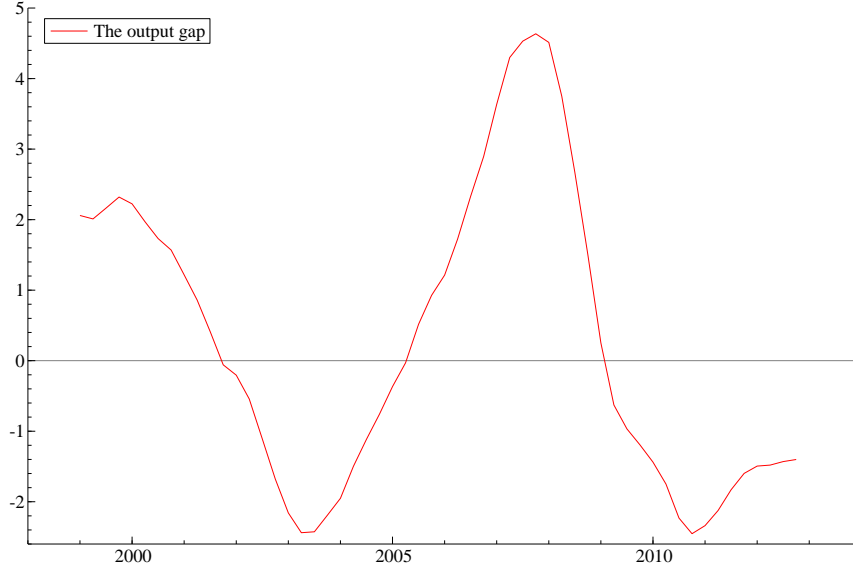


Figure 3 shows the movements in the output gap for our sample period.

#### 5.1.4 Additional information variables

In addition to these main variables, we use other variables to carry out the empirical analysis. We use the 1-year horizon world commodity price inflation and the spread between long and short term interest rates in Norway (from here on called the long-short spread) as instruments in our baseline model.<sup>6</sup> The world commodity price inflation is obtained from the International Monetary Fund's "International Financial Statistics" database while the spread is calculated from OECD-data on Norwegian short and long term interest rates.

Several other variables have been obtained to check if their presence as regressors can alter the empirical results. First, we look at the 3-month interbank lending rate in the euro area found in the OECD database as a proxy for foreign interest rates. In the empirical model, we use the 4 quarter log difference for this variable. Second, the import weighted currency, the I-44, measures the Norwegian currency against Norway's 44 biggest trade partners and is used as a measure for the Norwegian exchange rate. We got

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<sup>6</sup>The short term interest rate is in this case the NIBOR, while the long term interest rate is the 10 year bond

the monthly data from Norges Bank, and used the three month average to express it in quarterly terms. In the empirical model, we use the 4 quarter log difference for this variable.

Another variable we apply is a measure for the housing price deviation from trend, a housing price gap. We obtained the housing price index from Statistics Norway and created a HP-trend using a  $\lambda$ -value of 40 000. We also use the quarterly average of the Oslo Stock Exchange Benchmark Index (OSEBX), and find the four quarter log difference for this variable as a proxy for the equity return in Norway. We also look at debt per capita, which is obtained by taking the total household debt in Norway obtained from Statistics Norway, and dividing it by the number of citizens. Then, we found the four quarter log difference to create the variable series. Figures 4, 5 and 6 display all the additional information variables, and how they move relative to the interest rate.

We also test alternative variable measures of some of the variables presented so far, in the empirical analysis.

## 5.2 Sample periods and structural breaks

Although Norges Bank officially started inflation targeting in 2001, most economists agree that inflation targeting was implemented as Svein Gjedrem was appointed governor of the Norwegian central bank in January 1999. In fact he said so himself, when he expressed that in order to stabilize the Norwegian currency, inflation must be brought down to the level of other European countries (Gjedrem, 1999). That is the reason why our baseline sample period is 1999Q1 - 2012Q4, instead of 2001Q2 - 2012Q4. In addition, more observations yields more reliable results.

We want to learn whether the parameters in our reaction function are stable, in particular whether the parameters have been affected by changes in the Norwegian economy. The financial crisis, which erupted in the late third quarter of 2008, when Lehmann Brothers collapsed on September 15th, may have changed how the central bank conducts monetary policy and gives us a reason to search for a potential structural break in this period. Another potential structural break could be when Norges Bank changed their time horizon for the inflation target from 2 years to 1-3 years in the second quarter of 2004. A third possible structural break would be when Øystein Olsen took over for Svein Gjedrem as governor for Norges Bank. However, because this happened in January 2011, and because we end our estimation in the fourth quarter of 2011 because of the leaded inflation variable, we do not have enough data to work with. Hence this will be a topic better suited for future research.

Figure 4: Additional information variables

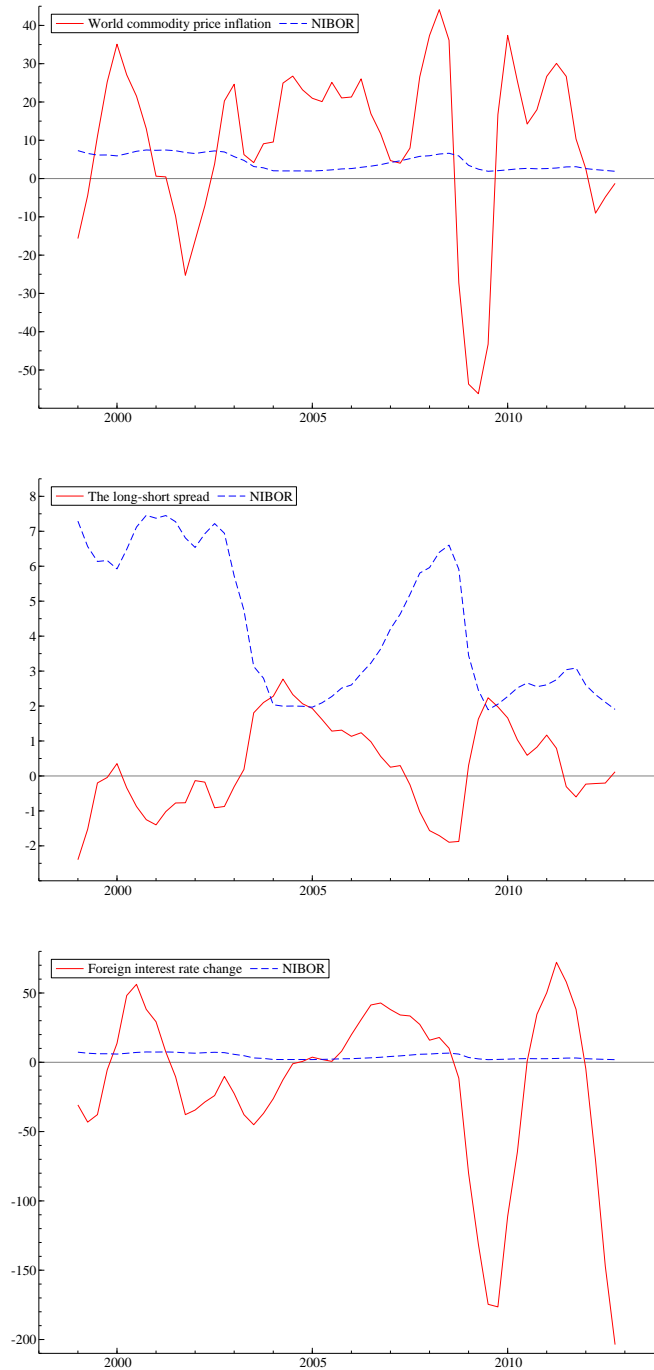


Figure 5: Additional information variables

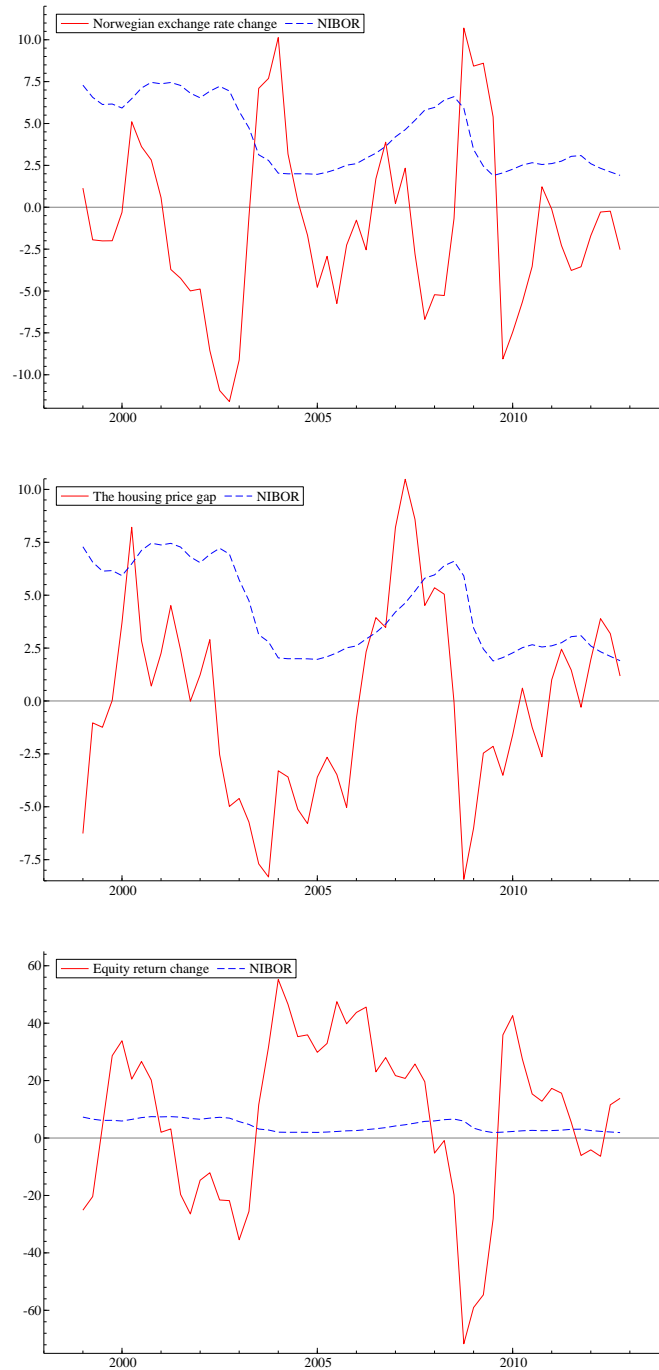
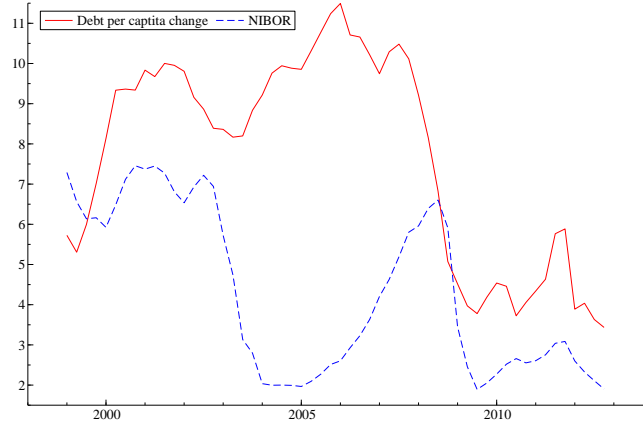


Figure 6: Additional information variables



### 5.3 Stationarity and unit root tests

Our econometric approach relies on the assumption that all the variables are stationary,  $I(0)$ . A variable  $y_t$  is stationary if (1)  $E(y_t) = \mu$ , i.e., the expected level is constant for all  $t$ , if (2) the variance is independent of time,  $Var(y_t) = \sigma^2$  and if (3)  $Cov(y_t, y_{t-s}) = Cov(y_t, y_{t+s}) = \gamma_t$  such that the covariance between periods is time independent. Stationary time series,  $I(0)$ , unlike processes that are integrated of order 1,  $I(1)$ , contains no unit roots.

Our main variables are the interest rate, the inflation rate and the output gap. In the appendix a formal test for stationarity is carried out and test results are given. We find that both for the output gap and for inflation we can reject non-stationarity at some lag levels by use of the augmented Dickey-Fuller (ADF) test. While the test do not reject non-stationarity for the interest rate variable, we stress that the ADF-test is known to have low power for variable series that are different from but close to  $I(1)$ . Hence the test often fails to separate near-integrated processes from non-stationary ones (Banerjee et al., 1993, ch.4).

## 6 Empirical findings

We will in subsection 6.1 first present how the original Taylor rule fits our data and the motivation behind this. In subsection 6.2 we present the findings from our baseline estimation. In subsection 6.3 we discuss the choice of instruments and how our baseline equations varies with the choice of instruments. In subsection 6.4 we discuss the choice of additional regressors, and in subsection 6.5 we present the results we get from adding these additional regressors. In subsection 6.6 we look at alternative horizons for inflation and the output gap, while in subsection 6.7 we discuss alternative variable measures and how these measures affect the results. In subsection 6.8 we look for structural breaks by performing estimations for different sample periods, and also by including dummy variables.

### 6.1 Fitting the original Taylor Rule

For motivational reasons, we first look at the coefficients suggested by Taylor (1993) and see how well they fit the actual interest rate. Although the original Taylor rule was extracted from U.S. data, the value of  $\lambda$  in equation (1) suggested by the monetary policy reports of Norges Bank, is not necessarily far off from such a rule. Recall from equation (4) that the constant coefficient in this case is 1, the inflation coefficient is 1.5 and the output gap coefficient is 0.5. Figure 7 presents the comparison. We see that although the fit is not perfect, the original Taylor rule does a remarkably good job.

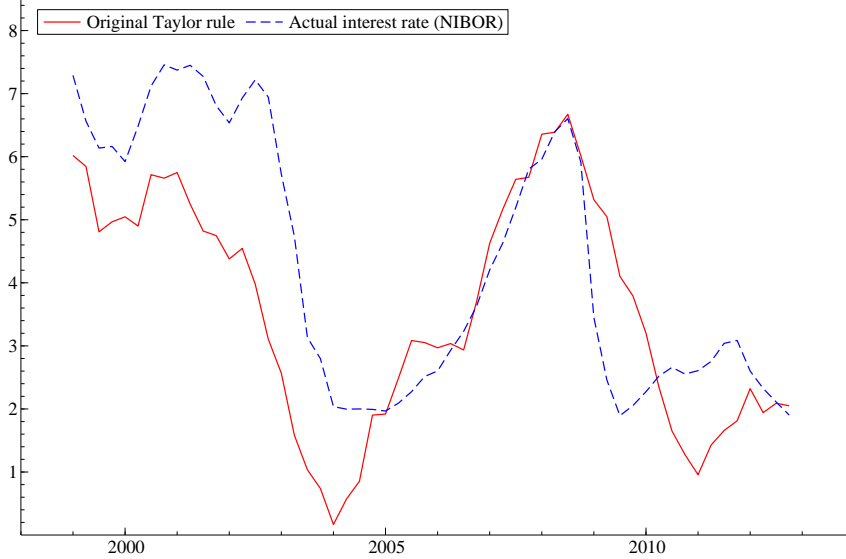
### 6.2 The baseline case

Following Clarida, Gali and Gertler (1998) and Clarida, Gali and Gertler (2000) we look at the forward looking Taylor rule where the left hand side variable is the interest rate and the right hand side variables are the 1 quarter lagged interest rate, a 1 year horizon annual inflation rate and a 1 quarter horizon output gap, corresponding to  $k = 4$  and  $q = 1$  in (8). The sample period is 1999Q1 - 2012Q4.

According to theory and past empirical results we would expect positive coefficients for both inflation and the output gap and naturally also for the lagged endogenous variable. The coefficient for the lagged endogenous variable is, however, expected to be below 1 as smoothing the interest rate is not the only objective. Because we use a 4-quarter forward term our estimation period ends after the fourth quarter of 2011.

The instruments we use in our baseline case are four lags of the interest rate, inflation, the output gap, world commodity price inflation and the

Figure 7: Fitting the original Taylor rule



short-long spread. This is a reasonable baseline instrument set as we expect neither the world commodity price inflation nor the long-short spread to directly affect the setting of the interest rate. It is exactly the same set of instruments used in Clarida, Gali and Gertler (2000), which makes the results comparable. This means that we use 21 instruments (including a constant term), and hence the model has more instruments than the number of estimated coefficients. Because of this we have to check whether the overidentifying restrictions are valid by means of the J-test. We estimate 4 parameters so the J-test has a  $\chi^2_{17}$  distribution under the null. The GMM estimation is done in EViews and we use the default settings when performing the analysis. We use time series (HAC) as weighting matrix which according to *EViews6 User's Guide II* (2007) will give estimates that are robust to heteroskedasticity and autocorrelation of unknown form. The kernel type is Bartlett and by the words of *EViews6 User's Guide II* (2007) this "determines the functional form of the kernel used to weight the autocovariances in computing the weighting matrix". The last option we have is the bandwidth selection which determines how the weights given by the kernel change with the lags of the autocovariances in computing the weighting matrix. Here we choose Newey and West's fixed bandwidth selection criterion. Table 1 shows the outcome.

In this specification the constant term and lagged interest rate are signif-



Table 1: Estimating (22) - the baseline case<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	$J - stat$ ( $J - prob$ )	SE of reg.
1.68** (0.79)	0.89*** (0.03)	1.06 (0.74)	0.96 (0.59)	8.97 (0.94)	0.517

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$   
Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments are four lags of nominal interest rates, inflation, output gap, world commodity price inflation and the spread between short term bills and long-term bonds.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

icantly greater than zero. Although neither the inflation coefficient nor the output gap are significant at a ten percent significance level, both are fairly close to being significant, respectively at 16 and 11 percent. The inflation coefficient is 1.06, the coefficient for output is 0.96 and the constant term is 1.68. The estimated smoothing parameter is 0.89, which suggests a high degree of monetary policy inertia, but the coefficient is significantly lower than unity. All coefficients have the expected signs.

The implied long run equilibrium nominal rate can be calculated by looking at the constant term:

$$\alpha = (i^* - 2.5\beta) \quad (31)$$

and inserting our estimated coefficients

$$1.68 = (i^* - 2.5 * 1.06) \quad (32)$$

Solving (32) for  $i^*$  we get

$$i^* = 4.33 \quad (33)$$

This is very close to the mean in the sample period, which is 4.29. It follows that the implied long run equilibrium real rate is

$$r^* = i^* - 2.5 = 1.83 \quad (34)$$

We see from Table 1 that the overidentifying restrictions passes the J-test in the baseline case as the J-probability is 0.94. By keeping in mind that the standard error of the baseline regression is 0.517, we can compare the

fit to other models later in this thesis. While our estimated coefficients have the right sign, we would expect the inflation coefficient to be somewhat higher and the output gap coefficient to be somewhat lower, considering that Norges Bank supposedly is targeting inflation first and foremost according to its monetary policy reports as described in subsection 2.1.

### 6.3 The choice of instruments

Although we suspect the instrument set used in the baseline model to be valid, in that they correlate with the regressors but not with the error term, it would be wise to check whether other instrument sets give different results, in other words, to test if our results are robust. We test several instrument sets for the baseline forward looking model. Our information set  $\Omega_t$  consists of the interest rate, inflation, the output gap, the world commodity price inflation, the long-short spread, foreign interest rates, the exchange rate, housing prices, equity return and debt per capita. Table 2 shows the results for some chosen instrument sets. We see that when the number of instruments is reduced, by removing 1 and 2 lags from the baseline instruments, neither the inflation nor the output gap coefficients are significant. In these cases only the lagged interest rate is a significant regressor. When using our whole information set of 10 variables, each with 4 lags, in addition to a constant as instruments, 41 instruments in total, the inflation coefficient is 1.86 and the coefficient on the output gap is 0.60. These results seem plausible and both coefficients are significant at a 1 percent level. The smoothing parameter is 0.87 and is also highly significant, as well as being significantly different from unity. The constant term is 0.68 and significant, which gives a long run real interest rate  $r^*$  of 2.83. In Table 2 we see that the coefficient values lie for the most part between 1.5 and 2 for inflation and between 0.5 and 0.9 for the output gap, when we use more instruments than in the baseline case. The smoothing coefficient is very robust to the choice of instrument sets with values between 0.87 - 0.93. The constant parameter, however, is apparently not very stable. We can conclude that the baseline forward looking model is quite robust to the choice of instruments. When adding instruments, we see that the estimations show that Norges Bank follows the Taylor principle as the inflation coefficient is above 1 in most cases. In addition the results suggest that Norges Bank puts more weight on stabilizing inflation than output.

The fear of adding too many instruments comes from the fact that some of the instruments may be weak, which can yield misleading estimation results. Mavroeidis (2004) argues that problems can occur when estimating forward looking Taylor rules when the predictable variation in inflation is

Table 2: Estimating (22) - different instrument sets<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	# of in- str.	$J - stat$ ( $J - prob$ )	SE of reg.
2.10 (2.83)	0.91*** (0.06)	1.15 (2.14)	0.79 (1.24)	11 <sup>b</sup>	5.53 (0.60)	0.526
3.20 (3.03)	0.93*** (0.05)	0.17 (2.42)	1.42 (1.59)	16 <sup>c</sup>	6.62 (0.88)	0.531
1.68** (0.79)	0.89*** (0.03)	1.06 (0.74)	0.96 (0.59)	21	8.97 (0.94)	0.517
0.79 (0.58)	0.87*** (0.02)	1.78*** (0.44)	0.68** (0.26)	25	10.39 (0.97)	0.515
1.48** (0.58)	0.89*** (0.02)	1.23*** (0.41)	0.89*** (0.24)	29	11.86 (0.99)	0.516
0.82* (0.43)	0.87*** (0.01)	1.78*** (0.27)	0.64*** (0.11)	33	12.59 (0.99)	0.515
0.63** (0.26)	0.87*** (0.01)	1.94*** (0.17)	0.57*** (0.09)	37	12.95 (0.99)	0.515
0.68*** (0.19)	0.87*** (0.01)	1.86*** (0.14)	0.60*** (0.09)	41	13.51 (0.99)	0.515

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita, respectively.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> The instruments are two lags of interest rates, inflation, the output gap, world commodity price inflation and the long-short spread.

<sup>c</sup> The instruments are three lags of interest rates, inflation, the output gap, world commodity price inflation and the long-short spread.

small relative to unpredictable future shocks. We mentioned in Section 4 that the instruments must be correlated with the right hand side variables, but not with the error term. Hence, when using all these instruments we assume that the lags included in the instrument set correlate with our forward terms. A correlation matrix is given in the appendix to show that this is the case. The theoretical argument is that the central bank does have access to all these variables and uses most of them to predict future inflation and output, and then uses these predictions to set the interest rate.

If we believe that Norges Bank reacts to other variables when setting the interest rate, then we should be careful when including instruments. In our baseline model we implicitly assume that lagged values of output gap, inflation, the interest rate, commodity price inflation and short-long spread do not correlate with the error term. If we include lagged values of other variables in the instrument set, we must make sure that their current value does not affect the interest rate setting decision. For example, let us consider a variable  $x$  which has a significant effect on the interest rate, but is not included as a regressor, thus effectively it is part of the error term. Its lagged values, which most likely correlate with the current value, are used as instruments. Hence, the instruments may correlate with the error term which violates the orthogonality condition. This is why some researchers, as for example Clarida, Gali and Gertler (1998) and Puckelwald (2012) when conducting GMM, only add lagged values to the instrument set *after* including the current value of the instrument as a regressor.

At this point it would be wise to introduce the J-test, which tests the validity of the overidentifying restrictions, that is whether the instruments are weak and if they violate the orthogonality conditions. Following Clarida, Gali and Gertler (1998) our null hypothesis for this test is that the central bank adjusts the interest rate each period so that equation (22) holds, with the expectations on the right-hand side based on all the relevant information available to policy makers at that time. This implies the existence of values for all our coefficients  $[\beta, \gamma, \rho, \alpha]$  such that the implied residual  $\epsilon_{1t}$  is orthogonal to the variables in the information set  $\Omega_t$ . Our alternative hypothesis will be that the central bank adjusts the interest rate in response to changes in some current and/or lagged variables, but not necessarily in connection with the information that those changes contain about future inflation and output. If so, then some relevant explanatory variables are being omitted from the interest rate equation. To the extent that some of those variables are correlated with our instrument set  $\mathbf{Z}_t$ , the set of orthogonality conditions will be violated, which would lead to a statistical rejection of the model given a sufficiently large sample. Clarida, Gali and Gertler (1998) claim that a failure to reject orthogonality implies that lagged variables enter the reaction

function only to the extent that they forecast future inflation or output.

From Table 2, we see that for none of the instrument sets suggested we can reject the overidentifying restrictions, hence all our instrument sets seems to correlate with the leaded variables, but not with the error term. This corresponds with Clarida, Gali and Gertler (1998) and Clarida, Gali and Gertler (2000) who use similar instrument sets, and a similar number of instruments.

## 6.4 The choice of regressors

There are reasons to believe that small open economies, more so than large economies, react to other variables than the output gap and inflation, for example exchange rates and foreign interest rates. The reasoning behind this is that small currencies are more vulnerable to speculation and that the fluctuations for these currencies are larger. Also, when a crisis occur, investors seek "safe havens" such as gold, the U.S. dollar or the euro. For example in Figure 5, we see that the exchange rate depreciated (corresponds to an increase in the exchange rate variable) when the financial crisis erupted, but have steadily appreciated from there on. A large appreciation of the Norwegian krone will hurt the export industry as it becomes relatively more expensive to buy from Norwegian exporters. Hence, we would expect a small open economy to follow closely the changes in foreign interest rates, as a high Norwegian interest rate relative to our trading partners will increase the demand for the Norwegian krone, and make the currency appreciate.

Clarida, Gali and Gertler (1998) add lagged inflation, money supply, foreign interest rates and the exchange rate when checking whether other variables should be used as regressors. They find that for most countries the baseline coefficients for inflation and the output gap do not change substantially when adding these variables as regressors. Siklos, Werner and Bohl (2004) estimate different Taylor rules for France, Germany and Italy with different instrument sets and argue that although some asset prices, such as real exchange rates and real estate prices are included in the reaction function as regressors and found to be significant, the results are not robust. Instead they find that adding alternative variables as instruments, not as regressors in a GMM estimation, makes the estimates more plausible and that they also achieve a better fit. They believe that these results suggests that the central banks did not directly respond to asset price developments, but that they influenced inflation and output gap expectations.

We consider the monetary policy reports by Norges Bank when choosing our additional regressors, and the results will be presented in the next subsection. First, Norges Bank tries in some degree to stabilize the Norwegian

exchange rate. In Norges Bank (2013) it says that "There is also a risk of a further appreciation of the krone. Should inflation be lower than projected, or the krone show a marked appreciation, the key policy rate may be reduced". Hence, an appreciation of the Norwegian krone should be followed by a lower interest rate and vice versa. We use the import weighted exchange rate index of the krone as a measure for the Norwegian currency. This index decreases when the Norwegian krone appreciates. An appreciation will induce a lower interest rate, hence we expect the coefficient to be positive when we include the exchange rate as a regressor in an estimated model. While the exporting industry in Norway pushes for a depreciation of the Norwegian krone, the main goal for Norges Bank is to keep the exchange rate somewhat stable.

The exchange rate is affected by foreign interest rates. A lower foreign interest rate, makes it more likely that investors want to keep their assets in the Norwegian krone as it yields a relatively higher return than other currencies. When the demand for the Norwegian krone is high then it appreciates, and Norwegian industry suffers because Norwegian goods are relatively more expensive. Hence, we expect both the currency and foreign interest rates to be significant, either as instruments that affect inflation and output expectations or as regressors. More specifically, if currency stabilization is a target then we should include lagged values of the foreign interest rates in the instrument set. The coefficient on foreign interest rates is expected to be positive in an estimated model.

There are also some concerns in Norges Bank that the housing prices are increasing at an unsustainable high level, which has resulted in increasingly higher debt per capita. We would expect the coefficients on this regressor to be positive, as a higher interest rate increases the cost of borrowing money and dampens the housing market. We will also try to include the commodity price inflation, equity return and debt per capita as additional regressors in the reaction function. If these variables are not targeted then they should not alter the other coefficients and the coefficients of these variables should not be significantly different from zero.

## 6.5 Including variables as regressors

In 6.5.1 we add our potential variables as regressors individually to see if they are significant and whether they change the other coefficient values or significance. In 6.5.2 we look at the case where two additional variables are added as regressors. Note that we are not searching for a perfect interest rule, but we want to see how the baseline coefficients and the additional coefficients behave in different specifications.

### 6.5.1 Including one additional variable as regressor

In table 3 we can see what happens when adding variables as regressors, estimating equation (25). When adding variables as regressors we also include 4 lags of the additional variable in the instrument set.

Table 3: Estimating (25) - adding variables as regressors<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	$J - stat$ ( $J - prob$ )	SE of reg.
Baseline	1.68** (0.79)	0.89*** (0.03)	1.06 (0.74)	0.96 (0.59)		8.97 (0.94)	0.517
<i>Adding:</i>							
Foreign I.R.	1.03* (0.58)	0.88*** (0.02)	1.80*** (0.40)	0.35** (0.14)	0.03*** (0.01)	10.49 (0.96)	0.473
Exch. rate	0.50 (0.30)	0.83*** (0.02)	1.91*** (0.22)	0.42*** (0.14)	-0.30*** (0.05)	9.72 (0.97)	0.421
Hou. prices	6.96** (3.29)	0.93*** (0.02)	-2.22 (2.30)	0.67 (0.43)	1.27*** (0.51)	11.23 (0.94)	0.443
Com. inf. <sup>b</sup>	-1.71 (1.15)	0.89*** (0.03)	2.36*** (0.63)	0.38* (0.21)	0.13*** (0.04)	9.22 (0.90)	0.434
Eq. return	-25.74* (14.55)	0.98*** (0.01)	14.06** (6.37)	0.41 (0.96)	0.55* (0.32)	10.07 (0.97)	0.467
Debt P.C.	-5.73*** (1.78)	0.84*** (0.02)	3.19*** (0.53)	-0.28 (0.20)	0.60*** (0.14)	11.11 (0.94)	0.494
Lagged inf. <sup>b</sup>	2.06* (1.20)	0.91*** (0.03)	2.09** (0.98)	0.80 (0.57)	-1.12 (1.04)	9.78 (0.88)	0.515

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$ . Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. When adding variables as regressors we include additional 4 lags of this variable to the instrument set.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> For world commodity price inflation and lagged inflation, the lags of these variables are already included in the instrument set, hence for these specifications the baseline instrument set is used.

Overall, we see that coefficients of the reaction function change a lot when adding some of the variables as regressors. When foreign interest rates are added to the Taylor rule equation we see that although the coefficient for this variable is highly significant, the value of the coefficient is seemingly low. The results say that when foreign interest rates rise by 1 percent the interest rate increases with 0.03. Note, however, that this is the 4 quarter log change, hence when foreign interest rates are low, small changes will yield

large log changes. For instance, if foreign interest rates increases from 0.5 to 1, then this is a 100 percent increase, which means that the Norwegian interest rate will increase by 3 percentage points according to the estimated coefficient. From this, we get that Norges Bank reacts stronger to foreign interest rate changes when this interest rate is low than when it is high. In this specification the inflation coefficient is larger than unity and the output gap coefficient is low, but positive and significant. The smoothing coefficient barely changes from the baseline case and is still highly significant.

When the exchange rate is added to the reaction function the coefficient for this variable is negative and highly significant. The result suggest that when the Norwegian krone appreciates, the interest rate is increased, which theoretically would lead to a further appreciation. Hence, the sign of this coefficient is not as expected. This is in line with the results of Puckelwald (2012) who finds this coefficient to have the "wrong" sign for 16 of the 20 countries he looks at, including Norway. In any case, the inflation coefficient in this specification is 1.91 and the output gap coefficient is 0.42, both highly significant. Again, the smoothing coefficient is high and significant. We see that for both these specifications, the values of the inflation coefficient and the output gap coefficient are not far from the ones we see when we use the full instrument set, see Table 2.

However, when including the housing price gap as a regressor, our original estimates change dramatically and it seems that our forward looking model breaks down. The inflation coefficient is now negative and insignificant, and although the output gap coefficient has the expected sign, it is insignificant. In addition, the coefficient for the housing price gap is unexpectedly high. Such a model suggests that if the housing price is 1 percentage point above the trend, interest rates increases with 127 basis points, which seems implausible. Although this result suggests that Norges Bank considers housing prices when setting the interest rate, we can not draw this conclusion as the coefficient of the other variables are insignificant, which very well may come from some sort of misspecification in the model.

We also include other variables in the reaction function that are not explicitly said to be targeted according to the monetary policy reports, but that potentially could have an effect. From Table 3 we see that when adding the world commodity price inflation to the reaction function its coefficient is highly significant and the value is 0.13, which means that a world commodity price inflation of 1% leads to the Norwegian interest rate increasing by 0.13 percentage points. In this specification, the inflation coefficient is higher than in previous specifications (2.36) and significant, and the output gap coefficient is positive and significant at a 10 % level. Still, the smoothing coefficient remains high and significant.



Including the equity return as a regressor renders the output gap coefficient insignificant, while the inflation coefficient is very high (14.06) and significant. The equity return coefficient is positive, but barely significant at a 10% level. The results suggest that Norges Bank increases the interest rate when equity returns increase, hence the coefficient has the expected sign. However, the smoothing coefficient is very close to unity in this specification, and we see from the value of some of the coefficients that the results are highly implausible.

When debt per capita is added to the reaction function the inflation coefficient is above 3 and highly significant, while the output gap coefficient is insignificant. The debt per capita coefficient is significant, and it suggests that a 1% increase for this variable increases the interest rate with 0.60 percentage points. However, because the constant term in this case is largely negative, we should be careful drawing conclusions. The smoothing coefficient is 0.84 and highly significant.

Including lagged inflation as a regressor yields results which suggest that while expected inflation is targeted, Norges Bank does not pay too much attention to what the inflation rate was in the last period. In this specification, the output gap coefficient is again insignificant.

### 6.5.2 Including two additional variables as regressors

We proceed by concentrating on variables mentioned in Norges Bank monetary policy reports, and try to add two additional regressors to the baseline case. The results are presented in Table 4 and we can see that both inflation coefficient and the output gap coefficient is significantly greater than zero when adding foreign interest rates and the exchange rate. The coefficients for these two additional regressors are also highly significant and their values are similar to the case where each of them are added separately. Note that this case yields the lowest standard error of regression. However the coefficient for the exchange rate still has the "wrong" sign.

When adding foreign interest rates and housing prices as regressors neither the inflation nor the output gap coefficient is significant. The coefficient for the foreign interest rate is close to what it is when added individually and significant, and the housing price coefficient is high and significant.

When the exchange rate and housing prices are added as regressors to the reaction function both of them are significant. However, the housing price coefficient is much lower than in previous estimations. In this specification both the inflation coefficient and the output gap coefficient is significant, although their values are lower than in previous models.

Table 4: Estimating (26) - adding 2 variables as regressors<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta_1$	$\eta_2$	SE of reg.
Baseline	1.68** (0.79)	0.89*** (0.03)	1.06 (0.74)	0.96 (0.59)			0.517
<i>Adding:</i>							
$i_t^f$ and $ex_t$ <sup>b</sup>	0.23 (0.21)	0.84*** (0.01)	2.16*** (0.15)	0.17** (0.08)	0.02*** (0.004)	-0.33*** (0.03)	0.371
$i_t^f$ and $hou_t$ <sup>c</sup>	5.59*** (1.61)	0.92*** (0.01)	-1.07 (1.04)	0.38 (0.26)	0.03*** (0.005)	0.92*** (0.16)	0.425
$ex_t$ and $hou_t$ <sup>d</sup>	1.85*** (0.59)	0.86*** (0.02)	1.14** (0.42)	0.24** (0.11)	-0.31*** (0.05)	0.39*** (0.11)	0.386

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta_1 h_{1t} + \eta_2 h_{2t}) + \rho i_{t-1} + \epsilon_{3t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively.  $i_t^f$  is foreign interest rates,  $ex_t$  is the exchange rate and  $hou_t$  is housing prices. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. When adding variables as regressors we include additional 4 lags of this variable to the instrument set.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> J-stat: 11.06, J-prob: 0.98

<sup>c</sup> J-stat: 11.75, J-prob: 0.97

<sup>d</sup> J-stat: 9.94, J-prob: 0.99

## 6.6 Horizons

Until now, we have looked at a 1-year horizon inflation variable and a 1-quarter horizon output gap. We want to check whether different horizons can have a significant effect on the empirical results. First we extend the inflation horizon to two and three years.

As the current horizon stated by Norges Bank is 1-3 years, we could expect a 2-year horizon to be a probable "average" horizon. Using the same instrument set (21 instruments) in our baseline forward looking model with a two year inflation horizon yields an inflation coefficient of 1.75 and an output gap coefficient of 1.10, both coefficients being significant at the 10% level. The lagged endogenous variable is again highly significant and has a coefficient of 0.91, significantly below unity. When using the whole information set the inflation coefficient is 0.85 while the output gap coefficient is 1.47, both statistically significant at the 1 % level. The result are shown in Table 5. We see that for various instrument sets most (disregarding the baseline instrument set) inflation coefficients have a value of about 0.8 - 1.2, while the output gap coefficients have a value around 1.3 - 1.5. This indicates that the Taylor principle in some of the specifications in Table 5 has not been followed, contrary to the 1-year horizon results.

This is an interesting result, but not a surprising result. If the central bank has a longer horizon for stabilizing inflation it will put more weight on stabilizing the output gap in the current period. Also, when changing the horizon, we "force" the estimation to focus more on the output gap and less on inflation than in the 1-year horizon case. Hence, these results suggest that if Norges Bank uses a 2 year horizon, it puts more weight on closing the output gap than stabilizing inflation. We now look at how the coefficients in the Taylor rule with a 2-year horizon inflation changes when adding variables, see table 6.

Including the foreign interest rates as regressors reduces the coefficient for output gap somewhat relative to the baseline case. However the inflation coefficient remains largely the same. In addition, we see that foreign interest rate has a somewhat larger effect than for the 1-year horizon inflation case and it is still significant. When adding the exchange rate, we see that the inflation coefficient becomes very high relative to the baseline case, while the coefficient for output gap is close to zero. Again we see that the sign for the exchange rate coefficient unexpectedly is significantly negative. If we add the housing price gap, we see that the results are similar to the 1-year horizon inflation case, as the inflation coefficient is negative and insignificant. Including the world commodity price inflation also has similar effects as in the 1-year horizon inflation case. When debt per capita is added we see

Table 5: Estimating (22) - different instrument sets, 2-year inflation horizon<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	# of in- str.	$J - stat$ ( $J-prob$ )	SE of reg.
0.30 (1.37)	0.91*** (0.02)	1.75* (1.01)	1.10** (0.54)	21	8.73 (0.95)	0.536
0.98 (1.14)	0.91*** (0.02)	1.18 (0.85)	1.38*** (0.45)	25	9.47 (0.98)	0.536
1.13 (0.90)	0.92*** (0.02)	1.14 (0.74)	1.37*** (0.40)	29	10.71 (0.99)	0.536
1.41* (0.77)	0.92*** (0.01)	0.86 (0.66)	1.44*** (0.37)	33	11.38 (0.99)	0.536
1.19* (0.60)	0.91*** (0.01)	1.04* (0.56)	1.36*** (0.32)	37	12.02 (0.99)	0.535
1.36*** (0.28)	0.91*** (0.004)	0.85*** (0.29)	1.47*** (0.13)	41	12.39 (0.99)	0.535

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2010Q4, as we end estimations 8 quarters prior to the latest available data because of the 8 quarter lead on inflation. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita, respectively.  $k = 8$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

Table 6: Estimating (25) - adding variables as regressors, 2 year horizon inflation<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	$J - stat$ ( $J - prob$ )	SE of reg.
Baseline	0.30 (1.37)	0.91*** (0.02)	1.75* (1.01)	1.10** (0.54)		8.73 (0.95)	0.536
<i>Adding:</i>							
Foreign I.R.	0.99 (1.20)	0.91*** (0.02)	1.65** (0.81)	0.64* (0.38)	0.04*** (0.01)	10.03 (0.97)	0.503
Exch. rate	-2.51** (1.07)	0.86*** (0.01)	3.89*** (0.78)	0.01 (0.19)	-0.40*** (0.06)	8.76 (0.99)	0.442
Hou. prices	5.89*** (1.82)	0.91*** (0.02)	-1.36 (1.19)	0.47 (0.32)	0.95*** (0.21)	10.69 (0.95)	0.457
Com. inf. <sup>b</sup>	-3.80 (2.80)	0.92*** (0.03)	2.94* (1.61)	0.78 (0.50)	0.18*** (0.06)	9.07 (0.91)	0.465
Debt P.C.	-13.30*** (2.51)	0.89*** (0.02)	5.85*** (0.61)	-0.68** (0.27)	0.97*** (0.21)	10.19 (0.96)	0.509
Lagged inf. <sup>b</sup>	0.16 (1.51)	0.91*** (0.02)	2.21 (1.85)	0.99 (0.66)	-0.35 (1.18)	8.65 (0.93)	0.543

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2010Q4, as we end estimations 8 quarters prior to the latest available data because of the 8 quarter lead on inflation. The instruments for the baseline case are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. When adding variables as regressors we include additional 4 lags of this variable to the instrument set.  $k = 8$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> For world commodity price inflation and lagged inflation, the lags of these variables are already included in the instrument set, hence for these specifications the baseline instrument set is used.

that the output gap coefficient is negative, which is theoretically implausible. In addition, the other coefficients are very high in absolute values, which suggest that this model is misspecified. Lagged inflation as a regressor is also insignificant for this horizon, which is also the case for leaded inflation and the output gap. We choose not to include equity returns in the table as a regressor, as this yields a smoothing coefficient of exactly one such that all other coefficients are highly insignificant.

The results from these estimations suggest that when additional regressors are implemented in a 2-year horizon specification, the inflation coefficient in most cases is larger than the output gap coefficient. In all cases where inflation is significant at the 10% level this holds. Only when housing prices are added the output gap coefficient is higher. However neither the inflation coefficient nor the output gap coefficient is significant in this case. The results contradict the results from the different instrument set specifications presented previously, which suggested that in a 2-year horizon specification, the output gap was most important for the central bank. We also note that the smoothing parameter is highly significant in all cases.

From table 7 we see that extending the inflation horizon to three years yields surprising results. We only include the baseline instrument set case and the full information set case in the table, to show that the results are theoretically implausible. Accordingly, we will not pay any more attention to specifications with three years inflation horizon

Focusing on the baseline model, we now look at a two-quarter horizon for the output gap, with the baseline instrument set and the full instrument set implemented. Table 8 shows the results. We see that using the baseline instruments yields a significant inflation coefficient which is larger than one. The output gap coefficient, however, is insignificant, while the smoothing coefficient is high (0.89) and significant. However, when the full instrument set is used, we see that the difference in the horizon specifications for output are very small. In the 2-quarter horizon case, the inflation coefficient and the output gap coefficient is 2.14 and 0.51 respectively, while they were 1.86 and 0.60 for the 1-quarter horizon case. This suggests however that if the instrument set is limited, output gap horizon changes will alter the results, as it did for inflation horizon changes.

## 6.7 Alternative variable measures

So far we have measured inflation by means of core inflation, CPIATE. Now, we replace CPIATE with CPI to create an alternative measure for inflation. We also try replacing the original output gap with an output gap created by a HP-trend with a  $\lambda$  of 1600. In addition, we look at the case where unem-

Table 7: Estimating (22) - 3-year inflation horizon<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	# of in- str.	$J - stat$ ( $J-prob$ )	SE of reg.
15.74*** (4.37)	0.92*** (0.02)	-10.39*** (3.55)	4.76*** (1.28)	21	8.67 (0.95)	0.518
13.46*** (0.66)	0.94*** (0.005)	-9.42*** (0.69)	5.13*** (0.38)	41	11.50 (0.99)	0.513

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2009Q4, as we end estimations 12 quarters prior to the latest available data because of the 12 quarter lead on inflation. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita.  $k = 12$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

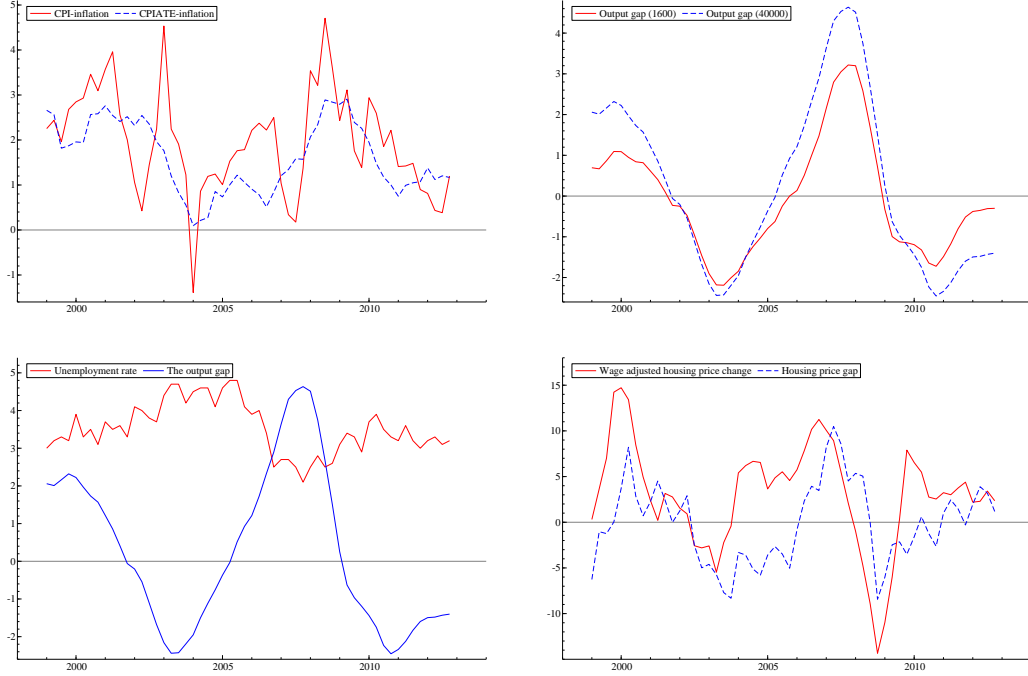
Table 8: Estimating (22) - 2-quarter horizon output gap<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	# of in- str.	$J - stat$ ( $J-prob$ )	SE of reg.
1.08* (0.54)	0.89*** (0.03)	1.53*** (0.53)	0.80 (0.51)	21	8.99 (0.94)	0.519
0.30 (0.17)	0.87*** (0.01)	2.14*** (0.12)	0.51*** (0.08)	41	13.47 (>0.99)	0.517

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita.  $k = 4$ ,  $q = 2$ . Values in parentheses are standard errors for coefficients.

Figure 8: Alternative variable measures



ployment replaces the output gap, in order to see if the results reflect the baseline case. Next, we look at an alternative measure of changes in housing prices to see if this new variable alters the other coefficients as much as the original housing price variable does. In particular we take the 4 quarter log change in housing prices minus the 4 quarter log change in nominal wages to create this new variable. Again, we look at the baseline model and use both the baseline instrument set and the full instrument set in two different estimations for all alternative variable measures. The four alternative variable measures are depicted in Figure 8, with the original variable included for comparison.

We see that coefficients change dramatically when replacing the CPIATE-index with the CPI-index. In particular the inflation coefficient becomes significantly negative when using the baseline instrument set, while the output gap is higher than in the baseline case and significant. Although the results are somewhat surprising, we can imagine that Norges Bank does not pay much attention to the CPI-index. Hence it is hard to make inference on these results. However, we see that the estimation results are conditional on the choice of price index.



Table 9: Estimating (22) and (25) - alternative variable measures<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	No. of instr.	SE of reg.
Baseline	1.68** (0.79)	0.89*** (0.03)	1.06 (0.74)	0.96 (0.59)		21	0.517
Baseline	0.68*** (0.19)	0.87*** (0.01)	1.86*** (0.14)	0.60*** (0.09)		41	0.515
<i>Variable change:</i>							
CPI	6.11*** (1.54)	0.92*** (0.01)	-1.70** (0.81)	2.19*** (0.56)		21	0.538
CPI	3.51*** (0.61)	0.91*** (0.01)	-0.32 (0.27)	1.59*** (0.15)		41	0.503
Output-1600	2.68** (1.01)	0.89*** (0.03)	0.73 (0.71)	1.58* (0.79)		21	0.496
Output-1600	2.52*** (0.48)	0.89*** (0.01)	0.82** (0.32)	1.76*** (0.28)		41	0.495
Unemp.	-1.97 (2.20)	0.83*** (0.03)	3.15*** (0.50)	0.29 (0.46)		21	0.534
Unemp.	2.26*** (0.62)	0.86*** (0.01)	2.54*** (0.12)	-0.67*** (0.12)		41	0.525
Wage adj. housing price <sup>b</sup>	-2.70** (1.28)	0.89*** (0.02)	3.41*** (0.57)	0.06 (0.22)	0.36** (0.14)	25	0.488

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients. J-stat(J-prob) for specifications:  $Base_{21}$ : 8.97(0.94),  $Base_{41}$ : 13.51(0.99),  $CPI_{21}$ : 10.12(0.90),  $CPI_{41}$ : 13.21(0.99),  $Output - 1600_{21}$ : 0.64(0.92),  $Output - 1600_{41}$ : 12.80(0.99),  $Unemp_{21}$ : 10.71(0.87),  $Unemp_{41}$ : 13.22(0.99), WHP: 11.37(0.94).

<sup>b</sup> Here, we estimate  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$ . When adding the variable as regressors we include additional 4 lags of this variable to the instrument set.

When we change the HP-filter for the output gap, we see again that coefficients change considerably. Now the output gap coefficient is much higher than in the case where  $\lambda$  is 40 000, both when we use the baseline instrument set and when we use the full information instrument set. The inflation coefficient is also lower than in the baseline case, and we see that it is substantially lower than the output gap coefficient. Hence, if we believe Norges Bank uses a  $\lambda$  of 1600 when measuring the output gap then this results suggest that stabilizing the output is more important than keeping inflation at target for Norges Bank.

We also try to implement the unemployment rate, by replacing the output gap. Unemployment is considered to be closely related to the output gap, and in theory unemployment should have a negative effect on the interest rate. In other words, we expect the coefficient for unemployment to be negative. The variable we use is obtained from the labor force survey of Statistics Norway. We see that inflation is highly significant in this specification, and that when using the full instrument set a one percentage point increase in the unemployment rate will lead to the interest rate being reduced by 0.67 percentage points, which seems plausible.

When applying the alternative housing price variable, we see that the inflation coefficient is larger than unity and highly significant. The output gap coefficient, on the other hand, is insignificant and close to zero in this specification. The coefficient for the new housing price variable is significantly positive and suggests that a 1% positive difference between the change in housing prices and the change in nominal wages, increases the interest rate by 0.36 percentage points. There can be several reasons why the results differ when using this alternative housing price variable. The most obvious is that the HP-filtered case does not directly take wage changes into consideration. However, during a recession, wage inflation will be dampened and the positive HP-trend will also be dampened, hence wages are indirectly considered in the housing price gap. In any case, we would expect wages to correlate with the housing prices, and Norges Bank is probably more interested in how housing prices changes in relation to wage changes, as the major concern is a housing bubble in which borrowers are not able to pay their debts.

The results for this subsection suggest that the model is very sensitive to different variable measures. In particular, we see that both the inflation and the output gap coefficient changes quantitatively. While earlier subsections suggest that inflation is the primary target for monetary policy, we see that a small change in the output gap measure can dispute these findings.

## 6.8 Sample periods

So far we have looked at the sample period 1999Q1 - 2012Q4. Now, we will look at whether the coefficients change if we split this period into two periods. Let us call the first period the pre financial crisis era, i.e., the period before the fourth quarter of 2008. One can argue that the financial crisis already started in late 2007, but in the case of a small open economy like Norway, most agree that it hit after the collapse of Lehman Brothers in September 2008. Hence, the other period, the post financial crisis era, is 2008Q4-2012Q4. We now go back to the baseline case with a 1-year horizon inflation and a 1-quarter horizon output gap from a HP-trend with a  $\lambda$  of 40 000.

Table 10: Estimating (22) - 1999Q1-2008Q3 - different instrument sets<sup>a</sup>

$\alpha$	$\rho$	$\beta$	$\gamma$	# of in- str.	$J - stat$ ( $J - prob$ )	SE of reg.
-1.17 (0.76)	0.82*** (0.02)	3.73*** (0.40)	-0.29 (0.18)	21	8.88 (0.94)	0.424
-1.16** (0.44)	0.85*** (0.01)	3.57*** (0.18)	-0.06 (0.12)	25	9.93 (0.98)	0.405
-0.75** (0.29)	0.89*** (0.01)	2.98*** (0.19)	0.46*** (0.14)	29	10.20 (0.99)	0.395
-0.74*** (0.13)	0.89*** (0.01)	2.98*** (0.07)	0.45*** (0.05)	34	10.24 (0.99)	0.395
-0.75*** (0.08)	0.89*** (0.003)	3.01*** (0.05)	0.42*** (0.05)	37	10.31 (0.99)	0.395
-0.71*** (0.05)	0.89*** (0.002)	2.96*** (0.03)	0.45*** (0.03)	41	10.35 (0.99)	0.395

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2008Q3. The instruments for the baseline case (21 instruments) are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita, respectively.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

We see from Table 10 which reports estimation results for the pre financial crisis era that for all instrument sets the coefficient for inflation is higher than in the baseline sample period, c.f. 2. Although the coefficient on the output

gap is not significant when using only our baseline instrument set, we see that as more instruments are included the output coefficient "stabilizes" at 0.4 - 0.5, which is lower than in the baseline sample period. Hence at first sight it seems as though inflation deviation was a bigger concern and that closing the output gap was a lesser concern before the financial crisis.

Table 11: Estimating (25) - 1999Q1-2008Q3 - adding variables as regressors<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	$J - stat$ ( $J - prob$ )	SE of reg.
Baseline	-1.17 (0.75)	0.82*** (0.02)	3.73*** (0.40)	-0.29 (0.18)		8.88 (0.94)	0.424
<i>Adding:</i>							
Foreign I.R.	-1.61*** (0.43)	0.90*** (0.01)	3.94*** (0.27)	-0.58*** (0.07)	0.10*** (0.01)	10.00 (0.97)	0.332
Exch. rate	-0.35 (0.37)	0.84*** (0.02)	2.80*** (0.26)	0.14 (0.14)	-0.20*** (0.03)	9.08 (0.98)	0.360
Hou. prices	1.79*** (0.42)	0.89*** (0.01)	1.78*** (0.23)	-0.15** (0.07)	0.48*** (0.06)	9.62 (0.97)	0.359
Com. inf. <sup>b</sup>	-1.39 (0.84)	0.83*** (0.02)	3.75*** (0.44)	-0.26 (0.19)	0.01 (0.01)	8.60 (0.93)	0.425
Eq. return	-1.01 (0.74)	0.84*** (0.02)	3.57*** (0.40)	-0.15 (0.16)	-0.01 (0.02)	9.75 (0.97)	0.414
Lagged inf. <sup>b</sup>	-0.19 (0.29)	0.65*** (0.04)	1.87*** (0.26)	-0.10 (0.11)	1.25 (0.14)	5.98 (0.99)	0.416

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2008Q3. The instruments for the baseline case are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. When adding variables as regressors we include additional 4 lags of this variable to the instrument set.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> For world commodity price inflation and lagged inflation, the lags of these variables are already included in the instrument set, hence for these specifications the baseline instrument set is used.

Next, we look at other model specifications with additional regressors as we did earlier for the full sample, see Table 11. When looking at the coefficient for the foreign interest rate we see that this is much higher in the pre financial crisis era than in the full sample period. This could be

related to the fact that the foreign interest rate was higher in this period. Hence, changes in percentages were smaller during this period than for the full sample. In this specification, however, the output gap coefficient becomes significantly negative, while the coefficient on inflation is close to 4.

Also in this sample period, we get the counter intuitive result of a negative coefficient on the exchange rate, but the effect is less than in the baseline sample period. The inflation coefficient is high and significant, while the output gap coefficient is insignificant.

It seems that housing prices were less targeted in this period as the coefficient for this variable is less than half for the full sample counterpart. In addition, the inflation coefficient is positive and significant for this sample period and specification. Again the output gap coefficient is significantly negative, though the value is small.

Neither the world commodity price inflation nor the equity return has a significant effect in this sample period and both coefficients are very close to zero. We choose not to include the results for the case when debt per capita is added as it yields highly implausible results, and the smoothing coefficient is close to unity. However, if we add lagged inflation to the reaction function we see that the corresponding coefficient is positive and highly significant. We see that in this case the smoothing coefficient is relatively low to what we see in the other models, which may suggest some sort of misspecification.

The results for the post financial crisis era are presented in table 12. Because we find the coefficients to be largely independent of which instrument set we use in the baseline model, we present only the case where variables are added as regressors.

The results from the post financial crisis era are interesting. Note, however, that we only have 12 observations in this case. Hence, the sample is very small and we should be careful drawing any conclusions. We see that in all specification the smoothing parameter is much lower than in previous cases, which points in the direction of the findings of Mishkin (2009, 2010) that the smoothing parameter is lower in times of financial crisis. In addition, we see that in the baseline case both the inflation and the output gap coefficient is negative and insignificant, which indicates that in times of crisis perhaps other variables are targeted. The inflation coefficient is significantly negative when foreign interest rates are added, while significantly positive and high when the exchange rate is added, which suggests that this sample period may be too small to be included in an empirical analysis.

We also introduce a dummy variable as a cross check to see if there really was a structural break at the time of the financial crisis, see table 13. The dummy variable has value 1 in the period 2008Q4 - 2010Q3, as an example period and 0 in all other periods. We see that the coefficient for the dummy

Table 12: Estimating (25) - 2008Q4-2012Q4 - adding variables as regressors<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	$J - stat$ ( $J - prob$ )	SE of reg.
Baseline	2.27*** (0.63)	0.67*** (0.10)	-0.08 (0.39)	-0.17 (0.18)		4.72 (0.86)	0.595
<i>Adding:</i>							
Foreign I.R.	5.85*** (0.98)	0.48*** (0.09)	-0.99** (0.39)	1.08*** (0.30)	0.01*** (0.002)	4.60 (0.87)	0.468
Exch. rate	-1.35 (0.71)	0.64*** (0.13)	2.80*** (0.68)	-0.15 (0.27)	-0.20** (0.06)	4.10 (0.85)	0.542
Hou. prices	3.35*** (0.83)	0.74*** (0.08)	-0.55 (0.50)	0.03 (0.32)	0.18** (0.06)	3.83 (0.92)	0.619
Com. inf. <sup>b</sup>	1.82** (0.67)	0.54*** (0.13)	1.46*** (0.35)	0.79** (0.27)	0.04** (0.01)	4.61 (0.80)	0.367
Eq. return	-2.85*** (0.70)	0.52*** (0.11)	0.81** (0.35)	-0.34** (0.12)	0.86*** (0.17)	4.67 (0.79)	0.529
Lagged inf. <sup>b</sup>	8.49*** (1.12)	0.65*** (0.08)	-1.18** (0.44)	1.32*** (0.27)	-1.38*** (0.21)	4.76 (0.78)	0.521

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 2008Q4-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments for the baseline case are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. When adding variables as regressors we include additional 4 lags of this variable to the instrument set.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> For world commodity price inflation and lagged inflation, the lags of these variables are already included in the instrument set, hence for these specifications the baseline instrument set is used.

variable is highly significant and negative. It suggests that in our chosen "crisis-period" the long run equilibrium interest rate was 3.30 percentage points lower than usual, which suggest that there really was a structural break.

Table 13: Estimating (22) - 1999Q1-2012Q4 - dummy variable<sup>a</sup>

	$\alpha$	$\rho$	$\beta$	$\gamma$	$\eta$	$J - stat$ ( $J - prob$ )	SE of reg.
Dummy <sup>b</sup>	1.01* (0.53)	0.82*** (0.02)	2.19*** (0.36)	0.13 (0.13)	-3.30*** (0.77)	8.83 (0.92)	0.488

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q} + \eta h_t) + \rho i_{t-1} + \epsilon_{2t}$   
Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The estimation is applied to quarterly Norwegian data for the period 1999Q1-2011Q4, as we end estimations 4 quarters prior to the latest available data because of the 4 quarter lead on inflation. The instruments are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

<sup>b</sup> Dummy has value 1 in period 2008Q4-2010Q3, and 0 for all other periods.

Next, we look at a potential structural break in the second quarter of 2004 when Norges Bank changed from a 2-year horizon inflation perspective to a 1-3 year horizon inflation perspective. However, because there are obvious signs of a structural break at the time of the financial crisis, we end this estimation in the third quarter of 2008. In particular the first sample is 1999Q1 - 2004Q2, while the other sample is 2004Q3 - 2008Q3. The results are presented in Table 14.

We see that the results from both estimations are implausible, which could have something to do with the smoothing coefficient being close to unity. Because of this, we cannot determine if there has been a structural break at the time of the horizon change, and whether coefficients have changed, hence we do not pursue this potential structural break any further.

## 6.9 Comparison of results for Norway

As mentioned before not many interest rate rules have been estimated in the case of Norway. However we want to compare the results from this thesis with previous results.

Table 14: Estimating (22) - 1999Q1-2004Q2 and 2004Q3 - 2008Q3<sup>a</sup>

Sample period	$\alpha$	$\rho$	$\beta$	$\gamma$	# of in-str.	SE of reg.
1999Q1-2004Q2	-31.25*** (10.60)	0.96*** (0.01)	18.79*** (5.46)	-5.49*** (1.87)	21	0.470
1999Q1-2004Q2	-31.69** (10.69)	0.96*** (0.01)	18.96*** (5.52)	-5.53*** (1.88)	41	0.470
2004Q3-2008Q3	4.25 (3.28)	0.99*** (0.01)	2.61* (1.41)	8.46 (7.10)	21	0.107
2004Q3-2008Q3	4.25 (3.28)	0.99*** (0.01)	2.61* (1.41)	8.46 (7.10)	41	0.107

<sup>a</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta\pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$

Rejection of the null-hypothesis at the 1, 5 and 10 percent significance level are denoted by \*\*\*, \*\* and \*, respectively. The instruments are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread. Then we add to the instrument set four lags of foreign interest rates, the exchange rate, housing prices, equity return and debt per capita.  $k = 4$ ,  $q = 1$ . Values in parentheses are standard errors for coefficients.

99 - 04<sub>21</sub>: J-stat(J-prob):7.78(0.97)

99 - 04<sub>41</sub>: J-stat(J-prob): 7.83(0.99)

04 - 08<sub>21</sub>: J-stat(J-prob): 5.63(0.96)

04 - 08<sub>41</sub>: J-stat(J-prob): 5.63(0.96)



Puckelwald (2012), with a sample period 1980Q1 - 2008Q4, finds in his forward looking model using GMM that for the baseline case only the lagged interest rate is significant, while inflation and output, though with positive coefficients, are not. When adding nominal exchange rate deviation from a natural level and real interest rate deviation from a base country as regressors, inflation becomes significantly positive, with a coefficient of 1.381. The coefficient for output is, however, still insignificant, neither is the one for the exchange rate gap. For the real interest rate deviation the coefficient is significant although the sign is not as expected. Puckelwald (2012) also estimates a backward looking Taylor rule with the same variables. In the baseline specification, the inflation coefficient is 1.04 while the output gap coefficient is 2.23, both significant. In the expanded Taylor rule specification the inflation coefficient is 1.32, while the output gap coefficient is 0.29, still both significant. The additional variables are also significant at a 10 percent level, though neither has the expected sign.

Bernhardsen and Bårdsen (2004) have a limited dataset, i.e., quarterly data from 1999 until 2004. When using only output gap, inflation and lagged interest rate as regressors in their backward looking model, they find a significant inflation coefficient of 2.82 and a non-significant output gap coefficient of -0.38. The smoothing coefficient is 0.67 and highly significant. Bernhardsen and Bårdsen (2004) argue that because their sample period is so small, they put a lot of weight on how they expect the coefficients to be and choose the most plausible models. For example, they replace the output gap with the output growth gap to find more plausible results. Bernhardsen and Bårdsen (2004) also discuss the trade weighted exchange rate and claim that including the exchange rate in a single equation model yields significantly wrong sign for the coefficient. The reason, they claim, is that there is a simultaneity problem. They show that when estimating a simultaneous model, the signs become as they first expected.

Bernhardsen and Gerdrup (2007) find that when performing estimations to find a neutral interest rate, the inflation coefficient is 2.2 and the coefficient for the output gap is 0.3. In this estimation they use quarterly data from January 1997 until 2006. This estimation is also a backward looking OLS-estimation and they do not include a smoothing parameter. They stress that the output gap coefficient is not statistically significant and that it is sensitive to the estimation period chosen.

Gagnon and Ihrig (2001) address the pass-through of exchange rate changes into domestic inflation for 20 industrialized countries from a time period of 1971Q1 until 2003Q3. Among other results, they find by using the IV-estimation method that the inflation coefficient for Norway is 0.6 with a standard deviation of 0.33, and that the output gap coefficient is -0.96 with

a standard error of 0.33, while the smoothing coefficient is 0.86 and highly significant. They also split the estimation into two subsamples where in the latest period, from 1990Q1 until 2003Q3 the inflation coefficient is 10.00 with a standard deviation of 8.22, while the output gap coefficient is 1.64 with a standard deviation of 2.97, hence none of them are significantly different from zero. The smoothing coefficient is in this subsample still highly significant and the value of the parameter is 0.85.

Table 15 shows how some of the baseline estimations in this thesis compare to previous estimations. We only state whether the coefficients are significant at the 10% level, as some of the previous estimations did not report standard errors. We see from table 15 that our pre financial crisis estimation with the full instrument set our result for the inflation coefficient resemble the one of Bernhardsen and Bårdsen (2004) when they include a smoothing parameter. They do however find a much lower smoothing parameter, and an insignificant output gap coefficient. For the specifications without interest rate smoothing by Bernhardsen and Bårdsen (2004) and Bernhardsen and Gerdrup (2007), they find, as we do for the pre financial crisis sample period, a high inflation coefficient, although in their case it is not statistically significant. Gagnon and Ihrig (2001) finds a significant inflation coefficient below unity. However they look at a time period from 1971, a period where inflation was not targeted. This goes for Puckelwald (2012) as well, as the sample start in this case is 1980. He finds a much higher smoothing coefficient than we do, and lower inflation coefficients. Because none of the comparable estimations have included the post financial crisis era we should be vary when comparing previous results to our full sample results, as we have shown earlier that there are signs of a structural break.

Table 15: Previous Taylor rule estimations for Norway<sup>a</sup>

Sample period	Author	Estimation method	$\rho$	$\beta$	$\gamma$
1971Q1-2003Q3	Gagnon and Ihrig	IV <sup>b</sup>	0.86*	0.60*	-1.96
1997Q1-2006Q3	Bernharden and Gerdrup	OLS <sup>c</sup>		2.2	0.3
1999M1-2004	Bernharden and Bårdsen	OLS <sup>c</sup>		2.2	-0.6
1999M1-2004	Bernharden and Bårdsen	OLS <sup>d</sup>	0.67*	2.82*	-0.38
1980Q1-2008Q4	Puckelwald	OLS <sup>d</sup>	0.935*	1.04*	2.23*
1980Q1-2008Q4	Puckelwald	GMM <sup>e</sup>	0.975*	1.20	13.48
1999Q1-2008Q3	This thesis	GMM <sup>f</sup>	0.89*	2.96*	0.45*
1999Q1-2012Q4	This thesis	GMM <sup>g</sup>	0.89*	1.06	0.96
1999Q1-2012Q4	This thesis	GMM <sup>f</sup>	0.87*	1.86*	0.60*

<sup>a</sup> Estimating Taylor rules. Rejection of the null-hypothesis at the 10 per cent significance level is denoted by \*. The coefficient for the constant term is not included in table.

<sup>b</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta E[\pi_{t,k}|\Omega_t] + \gamma E[x_{t,q}|\Omega_t]) + \rho i_{t-1} + \nu_{1t}$ . The instruments are lags of the interest rates, inflation and the output gap.  $k = 4, q = 4$ .

<sup>c</sup> Estimating  $i_t = \alpha + \beta \pi_t + \gamma x_t + \epsilon$

<sup>d</sup> Estimating  $i_t = \rho i_{t-1} + (1 - \rho)(\alpha + \beta \pi_t + \gamma x_t) + \epsilon$

<sup>e</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta \pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$ . The instruments are three lags of the interest rates, inflation and the output gap.  $k = 1, q = 1$ .

<sup>f</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta \pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$ . The instruments are four lags of the interest rates, inflation, the output gap, world commodity price inflation, the long-short spread, foreign interest rates, the exchange rate, housing prices, equity return and debt per capita.

<sup>g</sup> Estimating  $i_t = (1 - \rho)(\alpha + \beta \pi_{t,k} + \gamma x_{t,q}) + \rho i_{t-1} + \epsilon_{1t}$ . The instruments are four lags of the interest rates, inflation, the output gap, world commodity price inflation and the long-short spread.

## 7 Conclusion

In this thesis we have, inspired by Clarida, Gali and Gertler (1998, 2000), estimated different types of forward looking Taylor rules. We have checked for robustness by adding regressors, changing horizons, changing variable measures and changing sample periods. Although the evidence is not clear, we found for most specifications that for the sample period 1999Q1 - 2012Q4, Norges Bank reacted to both inflation changes and output gap changes. The inflation coefficient was above unity in most of the specifications, suggesting that Norges Bank has followed the Taylor principle. In addition there is evidence that Norges Bank put more weight on keeping the inflation rate close to the target than keeping the output gap close to zero. For the full sample period, we found that both foreign interest rates and the exchange rate appear to be significant as regressors in a Taylor type rule, although the sign for the exchange rate coefficient was unexpected. In addition, the variable created to measure the housing price deviation from trend was largely significant in the full sample period. However the inclusion of this variable as a separate regressor in the estimated reaction function rendered both the inflation and the output gap coefficients insignificant.

We also found that the flexible horizon for the inflation target of 1-3 years makes it hard to draw conclusions from the estimation results. The results from a 3-year horizon seemed highly implausible, and there are substantial differences for the coefficients when we considered a 1 year horizon inflation as opposed to a 2 year horizon. In particular, for the 2 year horizon the inflation coefficient was lower and the output gap coefficient was higher than in the 1 year horizon case, which is not surprising. The reason is that if Norges Bank has a 2 year horizon for inflation, it does not have to conduct monetary policy as aggressively as if it has a 1 year horizon. Hence, it can put more weight on stabilizing output. We also found that changing the horizon for the output gap from 1 to 2 quarters, changed the coefficients when using the baseline instrument set, although not much when using the full instrument set.

To check for robustness we also implemented alternative variable measures to check whether the results from our baseline model were robust. We found that for most cases, although the qualitative results rarely changed much, the size of the coefficients differed largely when using alternative measures for inflation and the output gap. In particular, when using a different parameter for the HP-trend for the output gap, we found that output may have been targeted as much as, or more than what inflation has. Additionally, the results were not robust to the choice of the housing price variable.

We also looked for structural breaks by splitting the full sample period at

the time of the financial crisis in the third quarter of 2008. There is evidence that inflation deviations from target was closed much more aggressively in the period before the financial crisis. The results from the post financial crisis time period suggest that other variables than inflation and the output gap were targeted, as the coefficient for both of these two baseline regressors are close to zero and insignificant. However because we end the estimation in 2011Q4 there are too few observations to make strong conclusions from this time period. In addition, we looked for a structural break at the time the inflation target horizon changed from 2 years to 1-3 years. No conclusive results could be obtained from this exercise.

When comparing the empirical findings to previous Taylor rule estimations for Norway, we cannot say whether or not our results are as expected. The reason is that the estimation results are largely dependant on the sample period, estimation method and model specification, and none of the previous literature are identical to the choices made in this thesis. Our results are however in most cases corresponding with the strategy reported in the Norges Bank monetary policy reports. However there are a number of reasons why the results presented in this thesis should be read with some reservations.

First of all, it is possible that we do not have enough variation in some of our variable series, hence the estimations can be misleading. As noted by Clarida, Gali and Gertler (2000):

Suppose, for example, that the Federal Reserve responds aggressively to large deviations of inflation from target but not to small deviations. Then by estimating over a time period where inflation does not vary much from its target, one might mistakenly conclude that the Fed is not aggressive in fighting inflation (i.e., one might mistakenly obtain too low an estimate of  $\beta$ ).

Another reason why we should be careful drawing conclusions is related to how our model is estimated. The estimation method used is generalized method of moments, which relies on the J-test of overidentifying restrictions to indicate whether a specification of a model can be rejected. When performing similar baseline estimations, Clarida, Gali and Gertler (1998) find that the overidentifying restrictions are not violated. When they add alternative regressors the coefficients hardly change. Hence they conclude that the baseline model to a large degree can describe the decisions of the Federal Reserve. In this thesis, we see that although the overidentifying restrictions are not violated for the baseline case, coefficients change substantially when adding alternative regressors. This suggests that the power of the J-test is limited in our context, as some of the estimated Taylor rules in this thesis may be misspecified.

Third, throughout this thesis we proceed as if all our variables are stationary. From the ADF-test we see signs of non-stationarity for the interest rate variable, which could be a possible reason for why the results are not very robust.

For future research we suggest looking for a structural break when the governor of Norges Bank was replaced in January 2011, when sufficient data has been made available. Another possible approach to achieve more robust findings could be to do a cointegration analysis in order to address the problem of potential non-stationarity for the interest rate. Other possibilities could be to test other variables as regressors in different combinations, and perform some forecasting exercises for those specifications that seem stable with regards to variable measures and sample periods.

In any case it is clear that none of the specifications considered in this thesis fully explains the variation in the interest rate, although the estimations in this thesis can give a good indication of the objectives and concerns of the Norwegian central bank.

## References

- Banerjee, Anindya, Juan J. Dolado, John W. Galbraith and David Hendry. 1993. *Co-Integration, Error Correction and the Econometric Analysis of Non-Stationary Data*. Oxford University Press.
- Belke, Ansgar and Jens Klose. 2010. “(How) Do the ECB and the Fed React to Financial Market Uncertainty? The Taylor Rule in Times of Crisis.” *Discussion Papers of DIW Berlin* 972 .
- Bernhardsen, Tom and Gunnar Bårdsen. 2004. “Sammenhengen mellom styringsrenten og makroøkonomiske variable: Noen enkle ligninger for Norge (The relationship between the policy rate and macroeconomic variables: Some simple equations for Norway).” *Staff Memo 2/2004, Norges Bank* .
- Bernhardsen, Tom and Karsten Gerdrup. 2007. “The neutral real interest rate.” *Norges Bank Economic Bulletin* 78:52 – 64.
- Biorn, Erik. 2012. “A note on the generalized method of moments (GMM).” *University of Oslo* .
- Castelnuovo, Efram. 2003. “Taylor rules, omitted variables, and interest rate smoothing in the US.” *Economics Letters* 81:55–59.
- Castelnuovo, Efram. 2007. “Taylor Rules and Interest Rate Smoothing in the Euro Area.” *The Manchester School* 75:1–16.
- Chadha, Jagjit S., Lucio Sarno and Giorgio Valente. 2004. “Monetary Policy Rules, Asset Prices and Exchange Rates.” *CDMA Working Paper Series 0403* .
- Clarida, Richard, Jordi Gali and Mark Gertler. 1998. “Monetary policy rules in practice - Some international evidence.” *European Economic Review* 42:1033 – 1067.
- Clarida, Richard, Jordi Gali and Mark Gertler. 2000. “Monetary policy rules and macroeconomic stability: evidence and some theory.” *The Quarterly Journal of Economics* 115:147–180.
- de Losso, Rodrigo. 2012. “Questioning the Taylor rule.” *Working Papers, Department of Economics 2012(22), University of São Paulo (FEA-USP)* .
- English, William B., William R. Nelson and Brian P. Sack. 2003. “Interpreting the Significance of the Lagged Interest Rate in Estimated Monetary Policy Rules.” *The B.E. Journal of Macroeconomics* 3.
- Esanov, Akram, Christian Merkl and Lucio Vinhas de Souza. 2005. “Monetary policy rules for Russia.” *Journal of Comparative Economics* 33:484–499.
- EViews6 User’s Guide II*. 2007. Quantitative Micro Software, LLC.
- Gagnon, Joseph E. and Jane Ihrig. 2001. “Monetary Policy and Exchange Rate Pass-through.” *FRB International Finance Discussion Paper No. 704* .

- Gerlach-Kristen, Petra. 2004. "Interest-Rate Smoothing: Monetary Policy Inertia or Unobserved Variables?" *The B.E. Journal of Macroeconomics* 4.
- Gjedrem, Svein. 1999. "Economic Perspectives." Annual address by Governor Svein Gjedrem at the meeting of the Supervisory Council of Norges Bank, 18 February 1999.
- Gozgor, Giray. 2012. "Inflation Targeting and Monetary Policy Rules: Further Evidence from the Case of Turkey." *Journal of Applied Finance and Banking* 2:127–136.
- Hodrick, Robert J. and Edward C. Prescott. 1997. "Postwar U.S. Business Cycles: An Empirical Investigation." *Journal of Money, Credit and Banking* 29:1 – 16.
- Hofmann, Boris and Bilyana Bogdanova. 2012. "Taylor rules and monetary policy: a global "Great Deviation"?" *BIS Quarterly Review* .
- Islam, Mohammed Saiful. 2011. "Problems Involved in Estimating Taylor Rule with US Data." *International Review of Business Research Papers* 7:25–41.
- Jia, Dun. 2011. "Time-series Analysis of Swedish Central Bank's Interest Rate Operation Rule." *Global Journal of Business Research* 5.
- Maria-Dolores, Ramon. 2005. "Monetary Policy Rules In Accession Countries to EU: Is the Taylor rule a pattern?" *Economics Bulletin* 5:1–16.
- Mavroeidis, Sophocles. 2004. "Weak Identification of Forward-looking Models in Monetary Economics." *Oxford Bulletin of Economics and Statistics* 66:609–635.
- Mishkin, Frederic. 2009. "Is Monetary Policy Effective during Financial Crises?" *NBER working paper series* (14678).
- Mishkin, Frederic. 2010. "Monetary policy flexibility, risk management, and financial disruptions." *Journal of Asian Economics* 21.
- Norges Bank. 2012a. "Norges Bank's Monetary Policy Report 1/2012."
- Norges Bank. 2012b. "Norges Bank's Monetary Policy Report 3/2012."
- Norges Bank. 2013. "Norges Bank's Monetary Policy Report 1/2013."
- Puckelwald, Johannes. 2012. "The influence of the macroeconomic trilemma on monetary policy - A functional coefficient approach for the Taylor rule." *16th Conference of the Research Network Macroeconomics and Macroeconomic Policies (FMM)* .
- Rudebusch, Glenn D. 2002. "Term structure evidence on interest rate smoothing and monetary policy inertia." *Journal of Monetary Economics* 49:1161–1187.
- Seitz, Franz, Christina Gerberding and Andreas Worms. 2006. Monetary Policy and Real-Time Data: The Case of Europe, Asia and the US. In *Integration in Asia and Europe*, ed. Paul J.J. Welfens. Springer Berlin Heidelberg pp. 165–182.
- Siklos, Pierre L., Thomas Werner and Martin T. Bohl. 2004. "Asset Prices in Taylor Rules: Specification, Estimation, and Policy Implications for the ECB." *Discussion Paper Series 1: Studies of the Economic Research Centre* (22).



- Smets, Frank. 2002. "Output gap uncertainty: Does it matter for the Taylor rule?" *Empirical Economics* 27:113–129.
- Su, Liangjun. 2012. "Generalized Method of Moments (GMM) estimation." *Singapore Management University* .
- Taylor, John B. 1993. "Discretion versus policy rules in practice." *Carnegie-Rochester Conference Series on Public Policy* 39:195–214.
- Weise, Charles and David Krisch. 2010. "The Monetary Policy Response to Changes in Credit Spreads." *Mimemo, Gettysburg College* .
- Yau, Ruey. 2010. "Estimating Forward-looking Taylor rule by GMM with Factor Instruments." *International Conference On Applied Economics – ICOAE 2010* .

## 8 Appendix

### 8.1 Data appendix

$i$  - Quarterly average of the 3-month Norwegian inter bank offered rate, in annual percentages. Source: OECD database.

$\pi$  - Core inflation in Norway. Expressed as a 4 quarter log difference from price indexes CPIJAE and CPI, in percentages. Source: Statbank, Statistics Norway.

$x$  - Output gap in Norway. Measured as a percentage deviation from a trend. The trend is a HP-trend with a smoothing parameter of 40 000 (1600 for alternative variable) created in Eviews. Source: Statbank, Statistic Norway.

$s$  - Long-short spread in Norway. The difference between 10 year Norwegian bonds and the NIBOR. Source: OECD database.

$o$  - World commodity price inflation. Expressed as a 4 quarter log difference from a price index in percentages. Source: IMF's International financial Statistics database.

$hou$  - Housing price gap in Norway. Measured as a percentage deviation from a trend. The trend is a HP-trend with a smoothing parameter of 40 000 created in Eviews. Source: Statbank, Statistics Norway.

$i^f$  - Foreign interest rates. The 4 quarter log difference of the euro-are 3 month interbank rate. Source: OECD database.

$ex$  - Norwegian exchange rate. The 4 quarter log difference of the I-44 (the import weighted currency index). Source: Norges Bank

$eq$  - Equity return. The 4 quarter log difference of the OSEBX. Source: OECD database.

$d$  - Debt per capita gap in Norway. The 4 quarter log difference of debt per capita. Source: Statbank, Statistics Norway.

$u$  - Unemployment rate from the Labor Force Survey. Source: Statbank, Statistics Norway

*wag* - Nominal wages. Expressed as a 4 quarter log difference to be included in the alternative housing price variable. Source: Statbank, Statistics Norway.

## 8.2 Testing for non-stationarity - The ADF test

To test for non-stationarity we have employed the augmented Dickey Fuller test. We have:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{p=1}^P \delta_p \Delta Y_{t-p} + \epsilon_t \quad (35)$$

where  $\alpha$  is a constant and  $\beta$  is the time trend coefficient. Our null hypothesis is that  $|\gamma| = 0$ , i.e., that the time series is not stationary. Our alternative hypothesis is that  $|\gamma| \neq 0$ , namely that the time series  $Y_t$  converges to a stationary time series. In the ADF-test we allow for lags to correct for potential serial correlation, and because we look at inflation from a 4 quarter perspective we use 4 order of lags. The results from the ADF-test are given in 16

It is natural to use 4 order of lags because we initially look at inflation from a 4 quarter perspective. Our results are given in Table 16.

We see that for the 1-year inflation non-stationarity is rejected when 3 lags are included. We can not however reject non-stationarity at any lag level for a two year horizon inflation within 4 lags. For the 3-year inflation, non-stationarity is rejected when 4 lags are included. For the various output gap measures we can reject non-stationarity for most lag specifications. This is not true for the unemployment rate variable, where we fail to reject non-stationarity for all lag specifications. For the interest rate, we cannot reject non stationarity at any lag level, hence according to the ADF-test we have that the output gap measures, the 1-year inflation and the 3-year inflation is  $I(0)$ , while for the other variables we cannot reject that they are  $I(1)$ . All our other variables are differences or HP-filtered gaps, and are all stationary by the view of the ADF-test, hence they are not included in the table.

## 8.3 The J-test

Here we show how the J-statistic is calculated, and the explanation follows Su (2012). We want the optimal weighting matrix  $M$  that minimizes the asymptotic covariance matrix:

$$\mathbf{V} = (\mathbf{D}'\mathbf{M}\mathbf{D})^{-1}\mathbf{D}'\mathbf{M}\mathbf{S}\mathbf{M}\mathbf{D}(\mathbf{D}'\mathbf{M}\mathbf{D})^{-1} \quad (36)$$

Table 16: ADF-test for main variables

Lags		0	1	2	3	4	Constant	Trend
<i>Variable:</i>								
Inflation, year	1	-1.64	-1.99	-2.78	-2.92*	-1.86	Yes	No
Inflation, year	2	-1.23	-1.69	-2.83	-2.78	-2.85	Yes	No
Inflation, year	3	-0.63	-1.21	-1.86	-2.06	-3.17*	Yes	No
Inflation, CPI		-3.40*	-3.33*	-3.51*	-4.18**	-2.31	Yes	No
Output gap, 1 quarter	1	-0.95	-3.88**	-2.45*	-2.71**	-2.16*	No	No
Output gap, 2 quarters	2	-1.72	-2.79**	-2.46*	-2.99**	-1.94	No	No
Output gap, HP-1600		-1.07	-3.94**	-2.48*	-2.72**	-2.14*	No	No
Unemployment rate		-0.22	-0.16	-0.11	-0.07	-0.16	Yes	No
The interest rate		-1.27	-2.08	-1.89	-1.50	-1.78	Yes	No

<sup>a</sup> ADF-test for main variables. Level of significance \* = 5% and \*\* = 1%.

As it turns out, the answer is  $\mathbf{M} = \mathbf{S}^{-1}$ . The asymptotic covariance matrix then reduces from

$$\mathbf{V} = (\mathbf{D}'\mathbf{S}^{-1}\mathbf{D})^{-1}\mathbf{D}'\mathbf{S}^{-1}\mathbf{S}\mathbf{S}^{-1}\mathbf{D}(\mathbf{D}'\mathbf{S}^{-1}\mathbf{D})^{-1} \quad (37)$$

to

$$\mathbf{V} = (\mathbf{D}'\mathbf{S}^{-1}\mathbf{D})^{-1}\frac{\mathbf{D}'\mathbf{S}^{-1}\mathbf{D}}{\mathbf{D}'\mathbf{S}^{-1}\mathbf{D}} \quad (38)$$

which leaves us with

$$\mathbf{V} = (\mathbf{D}'\mathbf{S}^{-1}\mathbf{D})^{-1} \quad (39)$$

We construct the test statistic by letting  $\hat{\theta}$  be the GMM estimator. From our null hypothesis we expect that  $\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)$  is close to zero. Now we define the J-statistic as

$$J = nH_n(\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)) \quad (40)$$

where

$$H_n = \mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)' \mathbf{M} \mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t) \quad (41)$$

and  $n$  is the number of observations in the estimation. We know that  $\mathbf{M} = \mathbf{S}^{-1}$  hence the J-test statistic will be

$$J = n\mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t)' \mathbf{S}^{-1} \mathbf{g}_T(\boldsymbol{\theta}, \mathbf{y}_t, \mathbf{W}_t, \mathbf{X}_t) \quad (42)$$

The J-statistic has a chi square distribution

$$J_n \xrightarrow{d} \chi_{m-k}^2 \quad (43)$$

where  $m$  is the number of instruments and  $k$  is the number of parameters estimated. Hence, we reject the null hypothesis if the J-statistic is higher than  $\chi_{m-k}^2$  for our chosen level of significance.

## 8.4 Correlation matrix

Table 17: Correlation matrix<sup>a</sup>

	$i$	$\pi(4)$	$x(1)$	$i^f$	$ex$	$hou$	$o$	$s$	$eq$	$d$
$i$	1	0.61	0.34	0.21	-0.21	0.33	-0.11	-0.88	-0.45	0.19
$\pi(4)$	0.61	1	0.73	0.30	0.13	0.64	-0.04	-0.61	-0.13	0.11
$x(1)$	0.34	0.73	1	0.39	0.06	0.63	0.13	-0.37	0.18	0.47
$i^f$	0.21	0.30	0.39	1	-0.02	0.47	0.51	-0.31	0.30	0.46
$ex$	-0.21	0.13	0.06	-0.02	1	-0.17	-0.41	0.21	-0.07	-0.11
$hou$	0.33	0.64	0.63	0.47	-0.17	1	0.23	-0.32	0.20	0.28
$o$	-0.11	-0.04	0.13	0.51	-0.41	0.23	1	0.07	0.67	0.25
$s$	-0.88	-0.61	-0.37	-0.31	0.21	-0.32	0.07	1	0.54	0.01
$eq$	-0.45	-0.13	0.18	0.30	-0.07	0.20	0.67	0.54	1	0.40
$d$	0.19	0.11	0.47	0.46	-0.11	0.28	0.25	0.01	0.40	1

<sup>a</sup> See data appendix for more information about the variables